Search and Competition Under Product Quality Uncertainty

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Abstract. I review models of consumer search and competition when product quality is uncertain and differs across firms. Although firms are vertically—and possibly also horizontally—differentiated, an appropriate symmetric price equilibrium with optimal consumer search can be neatly characterized. I propose a "random-quality" framework that unifies these models and discuss their insights on the operation of consumer search markets, focusing on (i) online advertising and search through platforms, (ii) the welfare effects of entry in search markets, and (iii) the role of quality observability under search frictions. I suggest directions for further research on these and related topics.

Keywords: consumer search, search cost, competition, product quality, firm quality, platform, entry, inspection goods, experience goods, quality observability.

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1. INTRODUCTION

The theory of industrial organization traditionally focuses on market concentration in analyzing barriers to competition. Increasingly, it is recognized that information frictions can be another significant source of market power. Starting from the seminal work of Stigler (1961), an extensive economics literature has studied search and competition in markets with consumer search cost. In a model of price competition for homogeneous products, Diamond (1971) demonstrates that the monopoly price prevails in equilibrium if all consumers must incur a positive search cost to learn each firm's price, whereas Stahl (1989) shows that if only some consumers have a positive search cost, oligopoly competition results in dispersed prices that are below the monopoly level but nevertheless increase in search cost. For markets with horizontally-differentiated products, Wolinsky (1986) shows that increases in search cost lead to higher equilibrium prices and lower expected match values for consumers. In these original contributions, firms are ex ante symmetric and offer products that have the same quality, even though consumers may have random utilities from a product. The analysis thus naturally concentrates on a symmetric price equilibrium, the tractability of which is also exploited in the subsequent literature.

More recently, there have been considerable efforts to incorporate firms that differ in product quality (i.e., with vertical differentiation) into models of consumer search. Product quality and its potential differences across firms are obviously relevant for consumer search, and they may become even more important in the contemporary economy, where digital technologies and the Internet have greatly expanded consumer choices, lowered entry costs, and reduced search frictions. While these changes offer great promises for efficiency gains and consumer benefits, the search for a desired product can be a daunting task for consumers in the online market, where the number of sellers is vast, their quality may vary widely, and product quality may be hard to determine before purchase. To analyze consumer search and competition in such environments, a challenge is that firms under vertical differentiation—unlike under horizontal differentiation—are not ex ante symmetric, which can substantially complicate the analysis. However, in one class of models, where product quality is uncertain and differs across firms, the analysis remains especially tractable. These models—discussed shortly—have shed new light on the operation of search markets, addressing questions including: How do search platforms shape advertising and consumer search in online markets? Will (further) reductions in entry cost or search cost improve product quality and consumer welfare? How does quality observability matter for price competition and welfare in search markets?

The models in this strand of literature follow what I call a random-quality approach, with the following simple structure: A product's quality is a random variable (ξ), which is high (H) with probability β and low (L) with probability $1-\beta$.[1] The realization of ξ is independent across consumers. A higher-quality firm has a higher β, so that its product is more likely to either (i) meet consumers' needs or (ii) be free of defects. Each firm's β may be its private information. A consumer's product value is u for H but is (normalized to) zero for L, where u is a random draw from a given distribution. Two alternative assumptions have been made on the dependence relationship of a consumer's u across firms: (i) u is identical for H by any firm, so that firms are only vertically differentiated, or (ii) u is independently distributed for each firm, so that firms are also horizontal differentiated. Firms simultaneously set prices. A consumer needs to search a firm with a positive search cost s in order to find its price, the realization of ξ, and her value u if $\xi = H$.[2] The models have desirable symmetry properties that permit fruitful analyses of consumer search and competition under product quality uncertainty with vertical differentiation. For this review, I will focus on three topics below:

(i) Advertising and search through online platforms. Athey and Ellison (2011) and Chen and He (2011) are two early papers that take the random-quality approach to study online advertising with consumer search. In their models, a platform (such as Google) can auction ad positions to firms that have private information about their qualities. In equilibrium,

[1] To economize notation, I sometimes also call a high-quality product H and a low-quality product L.

[2] Unless stated otherwise, the product is assumed to be an inspection good, for which consumers learn ξ from search. The approach also applies to experience goods, for which the consumer cannot observe ξ (e.g., whether the product has a hidden defect) before purchase but may still learn u for H from the product's observable features.

higher-quality firms, whose products are more popular or more likely to meet consumers' needs, bid higher and are placed on the platform in the order of their bids; and consumers will first search firms on the platform, in the order of their positions, before possibly randomly search other firms in the market. Therefore, in both papers, the platform serves as an information intermediary, directing consumers to (first) search more relevant sellers, which increases both search efficiency and expected output. While Athey and Ellison (2011) focus more on optimal auction design by the platform, Chen and He (2011) also shed light on the increasing importance of online platforms and their incentives. Search platforms have long existed (e.g., shopping malls), but the Internet has drastically increased the number of sellers that a consumer may consider for a potential purchase. Chen and He (2011) show that the platform's revenue increases in the number of firms (N) in the market,[3] offering an explanation for the enormous commercial success of online search platforms. They also find that the platform's revenue can vary non-monotonically with the relevance of search "keywords" and, hence, while the platform facilitates consumer search, it may lack the incentive to maximize search efficiency.[4]

(ii) Welfare effects of entry in search markets. Chen and Zhang (2018) present a random-quality model to study entry in search markets. While it is well known that free entry generally has ambiguous effects on social welfare when firms possess market power (e.g., Mankiw and Whinston, 1986), the standard view in economics has been that more entry will benefit consumers. Chen and Zhang (2018) show that search friction drastically changes the effects of entry on consumer welfare. The paper identifies two effects of increased entry—due to a marginal reduction in entry cost—in a search market: the marginal entrant expands the search varieties available to each consumer, but it also lowers the average quality of firms in the market and reduces search efficiency (as a consumer expects to search more firms

[3] When N is larger, a firm is less likely to be searched randomly by consumers. It is thus willing to pay more to be placed on the platform and at a top position to attract visits by consumers.

[4] This departure of the platform's incentive from the social optimum is analyzed more generally in Eliaz and Spiegler (2011), which presents a random-quality model with both vertical and horizontal differentiations. The literature has further shown that the platform may be biased in directing consumer search when, for instance, it is (partially) vertically integrated.

before finding a product that meets her need). Due to these variety and quality effects, free entry is excessive (deficient) for both consumer welfare and total welfare if entry cost is relatively low (high), and consumer welfare exhibits an inverted-U shape as entry cost rises. Therefore, when product quality is uncertain and differs across firms, contrary to the conventional wisdom, reductions of entry cost can actually *harm* consumers in search markets.

(iii) Implications of quality observability for consumer search and competition. The search literature typically assumes that by searching a firm consumers will observe its product quality (i.e., products are inspection goods). Chen et al. (2022) introduce experience goods to a random-quality model and investigate the implications of product quality and its observability for competition and welfare in search markets. While high quality is commonly associated with high price in traditional product markets, they show that in a search market increases in average firm quality will also raise equilibrium price for experience goods but will lower it for inspection goods, though in both cases consumer surplus and welfare will increase in firm quality. The authors further show that quality observability plays a crucial role in determining the welfare effects of search cost. In a setting where firms can invest in quality and establish quality reputation, for inspection goods both consumer surplus and total welfare rise as search cost decreases, consistent with the results in the literature. By contrast, for experience goods both consumer surplus and total welfare *fall* as search cost decreases if it is already relatively low.[5] The unconventional results on experience goods are especially relevant for some online markets where product quality is difficult to observe and low product quality coexists with low search cost. In these markets, (further) reductions in search cost may not benefit consumers, whereas regulations that impose quality standards and strengthen consumer rights could be more effective in improving market performance.

In Section 2 below, I describe in more detail the random-quality approach. In addition

[5] Although a reduction in search cost increases search efficiency and decreases price, it can reduce firms' incentive to invest in quality. If quality is observable before purchase, consumers can avoid the loss from a low-quality product by not purchasing it, in which case the search efficiency effect dominates. But if quality is unobservable before purchase, the quality effect dominates when search cost is relatively low.

to providing a unified structure for a class of search models with uncertain product quality, the framework also includes classic models such as Diamond (1971) and Wolinsky (1986) as limiting cases. In sections 3, 4 and 5, I discuss the random-quality models that respectively address the aforementioned three topics, as well as potential future research in these and related areas. Section 6 concludes.

2. A RANDOM-QUALITY APPROACH

The market contains a unit mass of consumers and a set Ω of firms. Each firm $i \in \Omega$ produces a single product, the quality of which, ξ_i, is high (H) with probability $\beta_i \in [0,1]$ and low (L) with probability $1-\beta_i$, where β_i is $i's$ private information and differs across firms. The realization of ξ_i is independent for each consumer. Specifically, each consumer's value for firm $i's$ product with quality ξ_i is

$$\upsilon_i(\xi_i) = \begin{cases} u_i & if \quad \xi_i = H \\ 0 & if \quad \xi_i = L \end{cases}, \tag{1}$$

where u_i is the realization of a random variable with a (marginal) probability distribution $F(\cdot)$ that admits density $f(\cdot) > 0$ on $[0, \bar{u}]$. Each consumer desires to purchase one unit of the product on the market, and can sequentially search sellers with perfect recall and—unless otherwise stated—in random order, incurring search cost s for each search (except for the first visit, which is free). By searching firm i, the consumer will learn $i's$ price, the realization of ξ_i, and value u_i if $\xi_i = H$.[6] Firms simultaneously and independently choose prices. Each firm may have a constant marginal cost c and a fixed cost, both of which are normalized to zero. Hence, a firm's price can be interpreted as its markup over marginal cost. For ease of exposition, we sometimes drop subscript i by referring a product's quality as ξ, a firm's quality as β, and a consumer's value for H as u.

We focus on two potential interpretations of product quality, depending on the relevant context. One is that a high-quality product (H) meets a consumer's need but a low-quality

[6] This assumes that the product is an inspection good, which is the default assumption, but the approach also allows analysis under alternative assumptions, which will be discussed as well.

product (L) does not. For example, if a consumer wishes to purchase a certain pair of running shoes, an H product could be one with the type and size that meet the consumer's need, though her value for it may still be the realization of a random variable. An alternative interpretation is that H contains no defect (or is well made) and will deliver its intended value (u) to consumers, but an L product is defective (or is poorly made) and will have no value to consumers.[7] Firms may also differ in quality, with a higher-quality firm having a higher β, either because its product is more likely to meet consumers' needs (or is more popular), or because its product is more likely to be defectless. Thus, the uncertainty in product quality leads naturally to a distinction between product quality and firm quality.

This framework, which builds on a formulation in Chen and Zhang (2017), contains a broad class of sequential search models that can be classified along several dimensions, including (a) the dependence relationship of each consumer's u across firms, (b) the values and possible differences of β across firms, (c) whether the quality or the number of firms is exogenously given or endogenous, and (d) the observability of product quality by consumers from search.

Consumer search and price competition for a homogeneous product can be considered as a limiting case in this framework, where $\beta = 1$ for all firms and each consumer's u for H from any firm is identical. In this case, consumers search sequentially to look for lower prices, but if all consumers have search cost $s > 0$, the unique equilibrium price is the monopoly price (Diamond, 1971), which in out context is

$$p^m = \lambda \left(p^m \right) \tag{2}$$

under the standard assumption that we maintain:

$$\lambda' \left(u \right) \leq 0, \text{ where } \lambda \left(u \right) \equiv \frac{1 - F \left(u \right)}{f \left(u \right)}. \tag{3}$$

[7] For example, for a pair of running shoes that a consumer orders from a seller, its actual size may differ from the stated size due to poor manufacturing quality; or an insurance policy that a consumer purchases from a firm may contain (hidden) exclusions that render the policy useless for a consumer in certain situations.

Each consumer will then end up searching only once, either purchasing the product if she finds her $u \geq p^m$, or exiting the market otherwise. Notably, in this homogeneous-product market, equilibrium price under Bertrand competition would be equal to marginal cost if there is no search cost. If search cost is $s > 0$ for some consumers—where s is not too high—but zero for others, then there is equilibrium price dispersion, and as s decreases, equilibrium prices fall monotonically and approach marginal cost when $s \to 0$, reconciling the Diamond and Bertrand outcomes (Stahl, 1989).[8]

If for every firm $\beta = 1$ and for every consumer u is an independent draw from $F(u)$ for all firms, the model becomes one of horizontal differentiation (**HD**), where consumers search sellers for higher match values (Anderson and Renault, 1999; Wolinsky, 1986). The focus is then on a symmetric equilibrium where all sellers set price p^* and consumers search sequentially with a reservation value u^*, where $u^* > p^*$ uniquely solves

$$\int_{u^*}^{\bar{u}} (u - u^*)\, dF(u) = s, \tag{4}$$

provided s is not too high.[9] As in homogeneous-good models, search cost is shown to be a major source of market power, with a higher s typically leading to a higher equilibrium price. Notably, with $s > 0$, equilibrium price is above marginal cost as the number of firms approaches infinite, exhibiting the defining feature of monopolistic competition.

For my discussion, I will focus on models where $\beta < 1$ and the values of β differ across firms. If each consumer's $u_i \equiv u$ for all i for which the consumer's $\xi_i = H$, we have search models of vertical differentiation (**VD**), where a higher-quality firm's product is more likely to be H, and a consumer's value for H from all sellers is identical. I will discuss how this

[8] In Varian (1980), search cost is either 0 or ∞ (after the first search). With $s > 0$ for some consumers, Stahl (1989) studies optimal sequential search by consumers. Chen and Zhang (2011) combine Varian and Stahl to assume three types of search cost: 0, s, and ∞. Then, in equilibrium consumers with s will sometimes search multiple sellers—unlike in Stahl where they only search once—and prices may rise as s falls.

[9] Other papers with **HD** models of consumer search include, for example, Haan and Moraga-González (2011) and Rhodes (2011). Arnstrong et al. (2009) analyze a variant of the **HD** model in which one of the firms is prominent and is first searched by consumers. Choi et al. (2018) study another variant of the **HD** model where consumers can observe sellers' prices before searching for match values.

model is used to study platforms as information intermediaries and their auctions of ad positions in markets with consumer search (Athey and Ellison, 2011; Chen and He, 2011).[10] I will also discuss the use of this model in Chen and Zhang (2018) to investigate the welfare effects of entry in search markets.

If each consumer's u for H from any firm is an independent draw from $F(u)$, then we have search models with both vertical and horizontal differentiations (**VHD**). These models can be further classified according to whether product quality (ξ) is observable to consumers from search: Consumers can learn product quality from search if the product is an inspection good (e.g., Eliaz and Spiegler, 2011),[11] and they can learn product quality only after consumption if it is an experience good (Chen et al 2022).[12] Anderson and Renault (2021) analyze an extended **VHD** model in which the distribution of a consumer's u for H differs across firms (i.e., it is $F_i(u)$ for firm i instead of $F(u)$), which creates additional vertical differentiation beyond differences in β, and they study an equilibrium where firms charge different prices.

The random-quality approach can also be adapted to situations where firm or product quality is potentially endogenous. This includes models that examine the incentives for a search platform to influence the values of β across firms, as in Chen and He (2011)'s **VD** model and Eliaz and Spiegler (2011)'s **VHD** model. This also includes models that examine the incentives for firms to invest in product quality and establish quality reputation, as in Chen et al. (2022)'s **VHD** model. Moreover, the approach can be used to study search markets where market structure is endogenous with entry (Chen and Zhang, 2018).

[10] The auction of ad positions by a search engine has been studied by Edelman et al. (2007) and Varian (2007), among others. Athey and Ellison and Chen and He first embedded such auctions in models of consumer search.

[11] While their main model is one of **VD**, Chen and Zhang (2018) also consider an extension with a **VHD** model.

[12] Chen et al. (2022) also consider the case of inspection goods as a benchmark. Still another possibility—the case of credence good—is that only an expert will know whether a product is needed for a consumer. Cao et al. (2022) analyze such a model, in which experts may "cheat" so that β is endogenous, but there is no horizontal differentiation because each consumer has the same value for a high-quality product from all expert sellers.

There are of course other ways to model product quality and their differences across firms in search markets. For instance, consumer utility from a product could be the sum of $q+u$, where (stochastic) quality q may differ between firms and the variable u corresponds to horizontally differentiated random values (e.g., Bar-Isaac et al., 2012), or quality can be introduced to an **HD** model, in which an increase in quality is represented by a stochastic increase in u through a shift in $F(u)$ (e.g., Zhou, 2022). Under the random-quality approach, each seller effectively competes in prices only for H with other sellers whose products are also H, or—in the case of experience goods—for some expected quality with other sellers that have the same expected quality. Since the product from different sellers is otherwise either homogeneous or differentiated only horizontally to the consumer, the price equilibrium is naturally symmetric. This can greatly facilitate the analysis of consumer search markets under vertical differentiation.

3. SEARCH PLATFORMS AS INFORMATION INTERMEDIARIES

We start with **VD** models in which a consumer's value for the product that meets her need (i.e., $\xi = H$) from all matched sellers is u. Sellers differ in quality (β). Chen and He (2011) analyze such a model, in which sellers may bid payments to a search platform (E) to be placed on its prominent positions. Consumers, who are looking for some product with a specific keyword, first search sellers on the platform in the order of their positions, before possibly searching other sellers. Each seller i, $i = 1, 2, ..., N$, is associated with a certain match probability β_i, the value of which is $i's$ private information. Equivalently, as in what follows, the N sellers can be (re)named as $S_1, ..., S_N$ so that $\beta_1 > \beta_2 > ... > \beta_N$, but the identity of S_i is unknown to consumers. E has $n < N$ positions E_1, $E_2, ...$, E_n, each of which can list a seller and the positions are allocated through a generalized second-price auction. Each consumer must incur a search cost to visit a seller.

In equilibrium, because all sellers who offer the product that meets a consumer's need has the same value (u) to the consumer, sellers all charge the same (monopoly) price p^m given by (2), following the logic in Diamond (1971). A seller who offers a more popular product, or with a higher β, will bid more to be placed at a higher position, because its product is more likely to yield a sale for a visiting consumer under the specific keyword, and the seller thus has a higher expected profit when searched by the consumer. Therefore, in equilibrium $S_1, ..., S_n$ are placed on E in a descending order, which reveals their quality types to consumers, and it is indeed optimal for consumers to first search sellers on E in the order of their positions. Paid-placement advertising thus improves search and market efficiency by (i) reducing consumers' expected search cost and (ii) increasing expected output because some consumers may then make purchases that are otherwise not made. The search platform essentially acts as an information intermediary that directs consumer search.[13]

The paper also finds that the platform's revenue from auctioning its ad positions is increasing in the number of firms in the market, N. When the market contains more firms, each of them is less likely to be searched randomly by consumers, and hence each is willing to bid more to be placed at prominent positions on the platform that are more searched by consumers. This provides an explanation for why online search platforms such as Google became enormously profitable: the Internet greatly expanded the number of sellers for a product, making search intermediaries much more important for both consumers and firms than traditional intermediaries such as a shopping mall.[14]

While the search platform can guide consumer search and improve welfare, its incentive may not coincide with the social optimum. As Chen and He (2011) show, if β_i is increasing in some common factor for all i, the search platform's revenue from position auctions can be an inverted-U function of the factor. Intuitively, as β_i rises, while the higher value of—say β_1—motivates S_1 to bid more to be placed at E_1, it reduces the chances that sellers at lower positions will be visited and potentially reduce their payments to E. Thus, even though welfare increases in β_i, the search platform may not want to maximize it. This point

[13] This is related to the idea that advertising can serve as a device to coordinate consumer search (Bagwell and Ramey, 1994).

[14] Rhodes et al. (2021) shows that when a multiproduct intermediary sells to consumers who demand multiple products, the intermediary is profitable even when it does not improve consumer search efficiency. This is because the intermediary can optimally stock high-value products exclusively to attract consumers, who are then also sold nonexclusive products that are relatively cheap to source from suppliers.

is shown more generally by Eliaz and Spiegler (2011) in a **VHD** model.

Athey and Ellison (2011) also analyze a **VD** model, showing that position auction by the search engine improves consumer search efficiency and welfare. Their model allows more general incomplete information about the possible values of the match probability (β). Consumers then need to form expectations about the values of $\beta_1, \beta_2, ...\beta_N$, even when they know from the position auction that the sellers with the highest match probabilities, $S_1, S_2, ..., S_n$, are placed at positions $E_1, E_2, ..., E_n$ on E. Furthermore, when a consumer does not find a match after inspecting a seller, say S_1, she may update her beliefs about the match probabilities of the remaining sellers. Consumers' search strategies and firms' bidding strategies are thus more sophisticated in their model. One of their simplifying assumptions is that sellers' prices are exogenously given. In equilibrium, a higher-quality seller bids more to be placed at a more prominent position that consumers will search early on, and consumers will indeed optimally search the sellers on the sponsored list in the order of their positions. Moreover, as in Chen and He (2011), consumer surplus and total welfare are higher if search costs are lower. In addition to establishing the existence of a symmetric pure strategy perfect Bayesian equilibrium for the model and characterizing the strictly monotone equilibrium bidding strategy of firms, Athey and Ellison (2011) also provide interesting new insights on auction design, especially on how to set the reserve price.[15]

In Athey and Ellison (2011) and Chen and He (2011), position auctions by a search platform provide efficient sorting of sellers. Other researchers have considered settings where the platform might be biased when trying to influence consumer search, because it is (partially) vertically integrated and wishes to direct consumers to its own products away from competitors' offerings or possibly due to other financial incentives (e.g., Burguet, Caminal, and Ellman, 2015; de Cornière and Taylor, 2014; Teh and Wright, 2022; White, 2013).

Another research direction is to relax the assumption that consumers can observe product quality when searching the firm. In many markets, products are "experience goods" for

[15] Other authors have also studied optimal auction design for search platforms (e.g., Gomes, 2014).

which the quality of a product may not be learned before purchase. This can be especially relevant with online purchases. For experience goods, a platform may no longer be able to perform efficient sorting of sellers, because a low-quality seller may have lower cost and can potentially receive a higher profit from attracting a consumer. This might explain the prevalence of low-quality products in some online platforms. For example, in a recent investigation by the U.S. Government Accountability Office (GAO), 20 of the 47 products purchased from third-party sellers on 5 popular consumer websites, including Amazon and Walmart, were counterfeits.[16] Apparently, in this example the online platforms have not been effective in sorting out the counterfeit sellers. It would be interesting for future research to study the role of search platforms and the optimal design of position auctions when the product possesses the feature of an experience good.[17]

More generally, a platform can design its information provision to affect consumer search and competition. For example, platforms can choose how to display ads, which product features or the level of information details to disclose, and algorithms or policies to improve the accuracy of product reviews. Dogan and Hu (2022) investigate this issue in a variant of the **HD** model, in which the platform is a search market where firms compete in prices and consumers search sequentially for horizontally differentiated products. By incurring a search cost, a consumer observes a firm's price and receives a noisy signal about the match value of its product. The platform designs the information disclosure rule that governs how this noisy signal is generated. The signal structure balances the dual roles of information in their model: more information improves the ability for consumers to find higher match values through search, which increases total welfare; but it also leads to a more differentiated market that softens competition, resulting in a higher equilibrium price. They characterize

[16] All 47 items purchased were advertised as new, brand-name items sold by independent sellers with average customer ratings above 90 percent, and all items were shipped from U.S. addresses (GAO-18-216, January 2018).

[17] Chen et al. (2022) analyze a model of consumer search for experience goods, in which they also examine the role of a search intermediary (without considerng position auctions). They find that the intermediary can improve welfare by screening out low-quality sellers when it can commit to a relatively small listing space on the platform, but it may lower welfare when lacking such commitment ability.

the signal structure that maximizes consumer surplus. It would be interesting to further study the platform's design of information provision when firms are vertically differentiated; i.e., they also differ in (random) product quality.

Furthermore, a platform's information provision may depend on the consumer data that can be collected both by the platform and by the sellers listed on them, which in turn depend on data regulations and consumer privacy protection policies. Understanding the interactions between the platform, the sellers, and regulatory polices, as well as their implications for consumer search and competition, is an interesting topic for future research.

4. EFFECTS OF ENTRY IN SEARCH MARKETS

Chen and Zhang (2018) show that search cost drastically changes how entry affects consumer welfare.[18] In a random-quality model with vertical differentiation, they identify two effects of increased entry—due to decreased entry cost—on consumer search: the marginal entrant expands the search variety available to each consumer, but it also lowers the expected quality of sellers in the market and reduces search efficiency. They show that due to these variety and quality effects, free entry is excessive (deficient) for *both* consumer welfare and social welfare when entry cost is relatively low (high), and consumer welfare initially *increases* in entry cost.[19]

In their **VD** model, there are $N \geq 2$ potential entrants, each of which can choose to become an active seller by incurring entry cost $k > 0$. Potential entrant i's product, $i = 1, 2, ...N$, will match each consumer's need (i.e., $\xi_i = H$) with probability β_i, and β_i is a random draw from $G(\cdot)$ with density $g(\cdot) > 0$ on support $[0, 1]$. A consumer's value for a matched product is u, which is randomly drawn from $F(u)$ and is identical for all

[18]While it is well known that free entry can have ambiguous effects on efficiency (Mankiw and Whinston, 1986), the standard view in economics has been that more entry will benefit consumers.

[19]When entry cost is low, the expected number of entrants is large while the marginal entrant's quality is much below the average quality. Hence, for a small increase in the entry cost, the search variety effect of entry is small but the search quality effect is large, implying that consumer welfare rises. The resutls are reversed when entry cost is high.

her matched sellers. As before, a consumer has zero value for a non-matched product (i.e., if $\xi_i = L$). Potential entrants first privately learn their realizations of β and then simultaneously choose either to enter the market or to stay out. This results in n active sellers in the market, who simultaneously and independently set their prices, after which consumers sequentially search sellers.[20] Each search will enable a consumer to discover whether a seller's product meets her need, her value u if $\xi = H$, and the seller's price. The model has a unique symmetric perfect Bayesian equilibrium, as I discuss next.

4.1 Market Equilibrium

Given k, a potential entrant will enter the market if and only if its quality (β) exceeds some threshold t. For a given t, the expected quality of an entrant is

$$\gamma \equiv \gamma(t) = \frac{\int_t^1 xg(x)\,dx}{1 - G(t)}, \tag{5}$$

where $\gamma > t$ for all $t \in [0, 1)$.

With the **VD** setting, the equilibrium price of each active seller will be p^m given by (2), and consumers will engage in search if s is not too high:

$$\gamma \int_{p^m}^{\bar{u}} (u - p^m)\,dF(u) \geq s. \tag{6}$$

Each consumer will search sequentially in random order and will purchase from the first match if $u \geq p^m$. The consumer will exit the market without purchase if $u < p^m$ or if she has searched all n sellers without finding a match.

In equilibrium, firm $i's$ expected profit for any given t when there are n entrants in the market (including i) is

$$\pi_n(\beta_i) = \beta_i \pi^m \phi_n, \tag{7}$$

where $\pi^m \equiv p^m [1 - F(p^m)]$, and

$$\phi_n = \frac{1}{n} \sum_{j=0}^{n-1} (1 - \gamma)^j = \frac{1 - (1 - \gamma)^n}{n\gamma} \tag{8}$$

[20] Although $n = 0$ is a possibility, the analysis focuses on situations where $n \geq 1$ and k is relatively small so that a potential entrant with a sufficiently high β will enter the market.

is the expected number of consumers who visit i when n firms ($n-1$ rivals) enter the market.

From (7), i's expected profit is increasing in β_i. The post-entry expected profit for i is

$$E\left(\pi|\beta_i\right) = \sum_{n=1}^{N} \delta_n\left(t\right)\pi_n\left(\beta_i\right), \tag{9}$$

where

$$\delta_n\left(t\right) = \binom{N-1}{n-1}\left[1 - G\left(t\right)\right]^{n-1} G\left(t\right)^{N-n} \tag{10}$$

is the probability that $n-1$ other potential entrants enter simultaneously as i. Because (i) an increase in the marginal entrant's quality will raise the average quality of all entrants in the market ($\frac{d\gamma}{dt} > 0$), and (ii) the marginal entrant's quality increases relatively more than the average seller's quality ($\frac{d(t/\gamma)}{dt} < 0$), under given n the expected profit for the marginal entrant is higher if it has a higher quality. That is:

$$\pi_n\left(t\right) = \pi^m \frac{t}{\gamma}\frac{1-(1-t)^n}{n} \tag{11}$$

increases in t. It can then be established that the expected post-entry profit for the marginal entrant is increasing in its quality: $E\left(\pi|t\right)$ increases in t.

For any given $k \in [0, \pi^m)$, there exists a unique threshold $t^* \equiv t^*\left(k\right) \in [0,1)$ that satisfies

$$E\left(\pi|t^*\right) = k, \tag{12}$$

and $t^* = t^*\left(k\right)$ increases in k, with $t^* = 0$ for $k = 0$ and $t^* \to 1$ as $k \to \pi^m$. Therefore, there exists a symmetric equilibrium where each potential entrant will enter if and only if its quality reaches the threshold t^*, and t^* monotonically increases in k. Moreover, there can be no other symmetric equilibrium.

4.2 Welfare Analysis

Define

$$\Phi = \int_{p^m}^{\bar{u}} \left(u - p^m\right) f\left(u\right) du; \qquad M\left(t\right) = 1 - \gamma\left[1 - G\left(t\right)\right], \tag{13}$$

where Φ is a consumer's expected surplus from a matched seller whose product meets her need, and $M\left(t\right)$ is the probability that a potential entrant will not be a match when the entry threshold is t. For a given t, consumer welfare, measured by expected aggregate consumer surplus (net of search cost), can then be expressed as:

$$V \equiv V(t) = \left[1 - M(t)^N\right]\left(\Phi - \frac{s}{\gamma}\right). \tag{14}$$

Equation (14) has an intuitive interpretation. The probability that a consumer will (eventually) find a match is $1 - M(t)^N$. Since Φ is the expected surplus to a consumer from a match and s/γ is the search cost adjusted by γ, $\Phi - s/\gamma$ reflects the expected net benefit from a search that yields a match. With a unit mass of consumers, V is the consumer's expected net benefit from the entry of firms under threshold t.

Given $F(u)$, s and N, V is entirely determined by t through $\gamma = \gamma(t)$ and $M(t)$. Totally differentiating $V(t)$ in (14) with respect to t:

$$\frac{dV}{dt} = \underbrace{-NM(t)^{N-1}\frac{dM}{dt}\left(\Phi - \frac{s}{\gamma}\right)}_{\text{search variety effect}} + \underbrace{\left[1 - M(t)^N\right]\frac{s}{\gamma^2}\frac{d\gamma}{dt}}_{\text{search quality effect}}. \tag{15}$$

The impact of an increase in t (i.e., an increase in k or a decrease of entry) on consumer welfare can thus be decomposed into two parts: a search variety effect and a search quality effect. An increase in t decreases the expected number of entrants, reducing consumers' search opportunities to obtain the expected net benefit $\Phi - s/\gamma$, where

$$\frac{dM(t)}{dt} = -\frac{d\gamma}{dt}\left[1 - G(t)\right] + \gamma g(t) = g(t)\,t > 0. \tag{16}$$

The second term, the quality effect, is the change in V due to $\frac{d\gamma}{dt} = \frac{g(t)(\gamma - t)}{1 - G(t)} > 0$, and hence a decrease in entry due to a higher t has a positive quality effect: an increase in t raises the average quality or match probability of sellers in the market, boosting consumer search efficiency. The change in consumer welfare from a marginal entrant depends on the balance of these two opposing effects. Remarkably, $V(t)$ given by (14) can be shown to be single-peaked.

Define $V^* = V(t^*)$ as the consumer welfare in the free-entry equilibrium. Since $t^*(k)$ is monotonically increasing, V^* is also a single-peaked function of entry cost k. Therefore, there exists some $k_V^o \in (0, \pi^m)$ such that relative to what maximizes consumer welfare, the expected number of entrants under free entry is too high when $k < k_V^o$ but too low when $k > k_V^o$. Furthermore, consumer welfare is an inverted-U function of k, first increasing and then decreasing, maximized at k_V^o.

As t, or entry cost k, decreases, more potential entrants choose to enter the market, but the marginal entrant has a lower quality. When k is high enough, entry is deficient and a decrease in k benefits consumers, both because the opportunity to search an additional entrant is highly valuable when the expected number of entrants is small and because the marginal entrant has a relatively high quality; hence the variety effect dominates. But when k is sufficiently low, the quality effect of entry dominates, so that entry is excessive and an increase in k benefits consumers.

Search cost is crucial for the consumer welfare results of entry. As search cost approaches zero, from (15) the search quality effect vanishes so that $dV/dt < 0$. Then, more entrants will always benefit consumers because of the positive variety effect. The entry cost (or the quality threshold) that maximizes consumer welfare increases in search cost and in the number of potential entrants. This is because with a high search cost, it is more costly for consumers to search more varieties, and thus fewer sellers with higher quality tend to be better for consumers, leading to a higher k_V^o (or t_V^o). Also, when N is high, the variety effect is less significant because for a given k the expected number of entrants is large, and hence an increase in t tends to be more beneficial to consumers, implying that t_v^o also increases in the number of potential entrants.

A parallel analysis in Chen and Zhang (2018) establishes that social welfare W can also exhibit an inverted-U shape as entry cost rises from zero. A marginal increase in k raises t^*, which reduces the expected number of sellers and the probability of sales for each consumer. Additionally, a higher k reduces an inframarginal seller's profit margin. Consequently, industry profit is reduced with a higher entry cost. However, a higher k will increase consumer welfare by raising t^* when $k < k_V^o$, which can potentially outweigh the profit effect. Hence, W can increase in k when k is small. But when k is large, profit and consumer welfare move in the same direction, and W falls as k rises.

4.3 Entry with Both Horizontal and Vertical Differentiation

Chen and Zhang (2018) further show that the welfare effects of entry in search markets can hold in a **VHD** model where each consumer has heterogeneous values for her matched sellers. Specifically, they consider a **VHD** model in which a consumer's value for each matched seller is independently and identically distributed on $[0, \bar{u}]$, with distribution $F(\cdot)$ and density $f(\cdot)$. Then, in addition to differences in firm quality, there is also horizontal differentiation among a consumer's matched sellers. Everything else is the same as in the main model.

A complication is that entry will now also affect equilibrium market price. Suppose first that there are $n \leq N$ sellers in the market who all set price p_n. Consumers' optimal search strategy is to sample sellers sequentially, with reservation value $a(\gamma)$ from each matched seller that satisfies

$$\gamma \int_a^{\bar{u}} (u - a) f(u)\, du = s. \tag{17}$$

A consumer stops searching when she finds a match with $u \geq a$; if no such product is found after she searches all sellers, she buys the product from the matched seller with the highest $u \geq p_n$, and she buys nothing if no match is found or if $u < p_n$ for all matches.

If $n = 1$, then the seller obviously charges the monopoly price; so $p_1 = p^m$. For $n \geq 2$, Chen and Zhang (2018) show that at any symmetric price equilibrium, each seller sets

$$p_n = \frac{[1 - F(a)]\, \varphi_n + \int_{p_n}^{a} [1 - \gamma + \gamma F(u)]^{n-1} f(u)\, du}{f(a)\, \varphi_n - \int_{p_n}^{a} [1 - \gamma + \gamma F(u)]^{n-1} f'(u)\, du}, \tag{18}$$

and consumers search with reservation value $a(\gamma)$ that satisfies (17). Furthermore, if F is a uniform distribution, then the symmetric price equilibrium exists and is unique.

For a given entry cost, when the equilibrium price is given by p_n in (24), there exists a free-entry equilibrium that is similar to the one in subsection 4.1, and the marginal entrant's quality, t^*, is now defined by (19) below.

$$\sum_{n=1}^{N} \delta_n(t^*)\, t^* p_n \frac{1 - [1 - \gamma + \gamma F(p_n)]^n}{n\gamma} = k. \tag{19}$$

Under plausible conditions, t^* increases in k, and consumer welfare initially increases but eventually decreases in t. The intuition is again the variety vs. quality trade-off: a lower t^* leads to a higher expected number of sellers but to lower average firm quality (γ) in the market. The increase in variety benefits consumers by expanding their search opportunities (which now also likely results in a lower price), whereas the decrease in firm quality harms consumers by reducing their search efficiency. As in subsection 4.2, when t^* is high and thus the number of active sellers is low, the variety effect tends to dominate, so that a further increase in t^* results in lower consumer welfare. On the other hand, when t^* is low, the quality effect tends to dominate, so that an increase in t^* results in higher consumer welfare despite the negative price effect. Since t^* increases in k, it follows that consumer welfare also first increases and then decreases in k. Social welfare can also be an inverted-U shaped function of k.

While the most novel result from this analysis is the effects of entry on consumer welfare, the finding about the effect of entry on social welfare also differs from those in several closely-related papers. In particular, Wolinsky (1984) studies the optimality of entry in a circle model with consumer search, where for simplicity he assumes that the price is exogenously given. He finds that the market will offer excessive variety when entry cost is sufficiently low. The reason is that in his model the socially optimal variety is bounded: when the number of varieties is sufficiently high (or the entry cost is sufficiently low), consumers will find a brand satisfying the sequential search stopping rule. In this case, an extra entrant will not benefit consumers and will reduce social welfare due to the negative business-stealing effect.

The models in Chen and Zhang (2018) also predict that entry is socially excessive when the entry cost is sufficiently small, but in their case entry can also be insufficient when the entry cost is relatively large. In both of their models, overentry in terms of social welfare occurs under low entry costs because the marginal entrant reduces the average quality of sellers in the market, reducing search efficiency (reenforcing the negative externality on profits); whereas deficient entry can arise under high entry costs because consumers benefit from more search opportunities to find a match, which can overcome the negative externality on profits.

The **VHD** model in Chen and Zhang (2018) is more closely related to Anderson and Renault (1999), who study an **HD** model with horizontally differentiated products. They find that market entry is always excessive. A key reason for the different results in the two models is that firms differ in quality in the **VHD** model with $\beta < 1$, whereas $\beta = 1$ for all firms in the **HD** model. The difference in firm quality (i.e., vertical differentiation) creates a search quality effect of entry that is absent in the **HD** model: the marginal entrant lowers the expected seller quality in the market so that entry can be excessive for consumers, and excessive entry for total welfare is still more likely due to the marginal entrant's negative effect on industry profit. On the other hand, since β is less than 1 for all firms, entry also has a positive output expansion effect (the marginal entrant may be a match for some consumers who would otherwise find no product that meets their needs), which explains why there can also be underentry in the market equilibrium of the **VHD** model.

Chen and Zhang (2018) argue that their results on how entry affects consumer welfare, while unconventional, is quite natural for search markets that include more broadly any market where firms have private information about product quality and consumers can obtain costly quality information before purchase.[21] In such markets, the severity of sellers' adverse selection problem is endogenous, depending partly on buyer's ability to acquire information. Consider, for example, Akerlof (1970)'s classic model of used-car market, where low quality sellers drive out high quality sellers under adverse selection. One may view Chen and Zhang (2018) as taking Akerlof's model a step further by adding consumer search to it, so that a buyer can incur a search or inspection cost to discover whether a car has a defect.[22] A high quality seller, whose car is less likely to be defective, then has a

[21] There are other related studies of product quality and consumer search. For example, in Wolinsky (1983), prices are observable before consumer search and may serve as signals of product quality that is privately known by firms. Dranove and Satterthwaite (1992) consider a search model where consumers can imperfectly observe prices and qualities after incurring search costs. They find that an improvement of price or quality information may either increase or decrease welfare.

[22] This, together with the consumer's idiosyncratic taste, may then determine whether the car will meet her need.

higher probability to result in trading and hence a stronger incentive to incur the entry cost to list its car for sale. The buyers' ability to learn a car's quality through costly inspection thus mitigates the adverse selection problem. But if entry cost is very low, it will not prevent low quality sellers from entering the market; buyers' search efficiency will then be too low and the market is likely to perform poorly. On the other hand, if entry cost is too high, very few sellers will enter the market, and even if their expected quality is high, it will be hard for buyers with heterogeneous preferences to find a match under the very limited search opportunities. This, in essence, is the trade-off between the search variety and search quality effects of entry. Crucially, the search quality effect arises only because asymmetric information on sellers' quality: if consumers knew sellers' quality, the entry of more firms, even of those with low qualities, would not reduce search efficiency, because consumers could then choose to search high-quality sellers first.[23]

Digital technologies and the Internet have drastically reduced entry costs in many markets. However, as I have discussed, in the presence of search cost, this may not increase consumer welfare, and it will not be unusual for entry restrictions to benefit consumers. This can shed light on many business practices. Consider, for instance, the market of apps for iPhones and iPads. Although more app developers will offer users more choices, the entry of low quality sellers can reduce search efficiency and make it harder for consumers to find a desired app. Apple, which clearly would benefit from higher consumer interests in using its app store, appears to balance this trade-off by both increasing entry cost—it charges a fixed fee to each developer—and maintaining quality through a stringent review process for apps to be listed on its online store. In addition to entry barriers created by private entities, government policies can also restrict low-quality entry, as for example with a minimum quality standard. A licence fee that acts as a transfer payment can also positively impact both consumer and total welfare by raising the quality of the marginal entrant.

[23] This suggests that directed search by intermediaries may be more important in markets with lower entry costs. More generally, it could be interesting to study how a platform may design its allocation of advertising positions under endogenous entry of sellers.

5. QUALITY OBSERVABILITY AND CONSUMER SEARCH

Models with random quality can also be classified according to whether product quality (ξ) is observable to consumers from search, or when the quality uncertainty is resolved. Consumers can learn quality during search if the product is an inspection good, they can learn quality only after consumption if it is an experience good, and only an expert seller will know the quality of advice if the product is a credence good. The search literature has mainly studied consumer search and competition for inspection goods. In this section, I discuss how the operation of the market may change in important ways when consumers search for experience goods.

Chen et al. (2022) analyze a **VHD** model, where the market contains a unit mass of firms that differ in random quality with $\beta < 1$, and a consumer's u for H from any firm is independently drawn from $F(u)$. The paper mainly examines the case of experience goods but also considers inspection goods as a benchmark, and it provides two main results: (1) An increase in the average firm quality in the market intensifies price competition for inspection goods but softens it for experience goods, and (2) in a two-period setting where firm quality is determined endogenously through investment and firms can establish quality reputation after the first period, decreases in search cost boost consumer and total welfare for inspection goods but can reduce both for experience goods.

5.1 Search under Exogenous Quality: Inspection vs. Experience Goods

The Case of Inspection Goods

In this case, by searching firm i, a consumer learns whether ξ_i is H or L, in addition to discovering $i's$ price and her value u_i if $\xi_i = H$. Assume that for all i, firm quality $\beta_i \in \left\{\beta^l, \beta^h\right\}$ with $0 < \beta^l < \beta^h < 1$, and β_i is i's private information. The average firm quality in the market is

$$\gamma = \alpha\beta^h + (1-\alpha)\,\beta^l, \tag{20}$$

where α is the exogenously-given fraction of firms with $\beta = \beta^h$ in the market. In a uniform-price equilibrium where each firm charges price p^*,[24] consumers' optimal search follows a reservation-value strategy, with the optimal reservation value u^* satisfying

$$\gamma \int_{u^*}^{\bar{u}} (u - u^*) f(u) \, du = s; \tag{21}$$

and obviously no consumer would purchase from i if $\xi_i = L$. The left-hand side of equation (21) is the consumer's expected benefit from one more search when she is currently at a seller with u^*, which decreases in u^*, while s is the marginal cost of the extra search. The condition extends the optimal search rule for horizontally differentiated products (e.g., Wolinsky, 1986), which is a special case of equation (21) when $\gamma = 1$. Under the maintained assumption that s is small enough, there exists a unique $u^* \in (0, \bar{u})$ that solves (21), and each consumer's expected surplus from search is $v^* = u^* - p^* > 0$.

To determine the equilibrium price, suppose that at p^* a firm, say i, deviates with price p. Under the standard passive belief assumption in consumer search for differentiated products (e.g., Wolinsky, 1986), the other firms are expected to continue to charge the equilibrium price p^* with the average quality γ unchanged.[25] A consumer visiting i will purchase if she finds $\xi_i = H$ (which occurs with probability β_i) and her value for it, u_i, satisfies

$$u_i - p \geq u^* - p^*.$$

Firm i's (expected) demand from any visiting consumer is thus

$$D(p, p^*) = \beta_i \left[1 - F(u^* + p - p^*)\right],$$

and it chooses p to maximize $pD(p, p^*)$. Under the maintained monotone hazard rate condition (3), this leads to a unique equilibrium price

$$p^* = \lambda(u^*), \tag{22}$$

[24] The analysis of search for inspection goods in a VHD model with given firm quality is closely related to other such studies (e.g., Chen and Zhang, 2018; Eliaz and Spiegler, 2011), which also consider only a uniform-price equilibrium.

[25] Janssen and Ke (2020) also assume a passive belief in a consumer search model in which firms may choose to provide a service that other firms can free-ride on. In their model, when observing a firm's deviation on service provision or/and price, consumers continue to believe that other firms maintain their equilibrium decisions

which is independent of $\beta_i \in \left\{\beta^l, \beta^h\right\}$.[26] Since a random visit by a consumer to a firm will on average result in a purchase with probability $\gamma\left[1 - F\left(u^*\right)\right]$, and since all consumers—whose total mass is one—will (eventually) purchase, the equilibrium output of firm i is $\frac{D(p^*,p^*)}{\gamma[1-F(u^*)]} = \frac{\beta_i}{\gamma}$, and its equilibrium profit is $\pi\left(\beta_i\right) = \frac{\beta_i}{\gamma}\lambda\left(u^*\right)$. Hence, a firm will have a higher profit than an average firm if $\beta_i = \beta^h$.

Since u^* increases in γ from (21), an increase of average firm quality in the market leads to a *lower* equilibrium price:

$$\frac{dp^*}{d\gamma} = \lambda'\left(u^*\right)\frac{\partial u^*}{\partial \gamma} \leq 0.$$

This is because when the average firm quality is higher, consumers are more likely to find $\xi = H$ from another search. This increases consumers' search incentive, intensifying price competition. On the other hand, for given γ, an increase in s reduces match value (u^*) and search intensity, which decreases competition and increases price.

In equilibrium, industry profit, consumer surplus, and total welfare are respectively

$$\Pi^* = \lambda\left(u^*\right); \qquad V^* = u^* - \lambda\left(u^*\right); \qquad W^* = u^*\ . \tag{23}$$

The Case of Experience Goods

In this case, consumers cannot learn whether $\xi = H$ or L (e.g., whether the product has some hidden defect) before purchase, even though by searching firm i a consumer will learn its product's price and her personal value u_i for H based on $i's$ observable product features (e.g., its color, size, and style). With the average quality of sellers in the market γ still given by (20), we again focus on a uniform-price equilibrium where all firms charge the same price p^*. Interestingly, consumers' optimal reservation value in search, u^*, again satisfies (20), the same condition as for inspection goods. This is because when arriving at a firm with $u = u^*$, the expected marginal benefit of an additional search is the same under inspection and experience goods.[27]

[26] This independence of the equilibrium price from firm quality (β), which is true also in other models of **VHD,** is an advantage of the random-quality approach that incorprates heterogeneous firm qualities in a tractable way.

[27] However, as we shall see shortly, equilibrium consumer surplus and total welfare are both lower for

Next, consider the pricing strategy by firms. At the candidate uniform-price equilibrium, suppose that firm i deviates to a price p. As before, consumers are assumed to hold the passive belief that the other firms will still charge p^* with average quality γ. Because the consumer cannot observe ξ_i before purchase, there is the additional issue of her belief about β_i.[28] Chen et al. (2022) extend the standard assumption to postulate that consumers also hold the belief that the deviating firm continues to have the expected quality γ. This additional condition on the passive-belief assumption is motivated by the observation that in the model here, if a price deviation is profitable for β^i with $i \in \{l, h\}$, it will be equally profitable for β^j with $j \neq i$. Thus, consumers have no reason to change their belief about the expected quality of the firm (γ).[29] Moreover, under this passive belief assumption, a uniform-price equilibrium survives standard equilibrium refinements such as the intuitive criterion and the D1 condition.

Now consider a consumer who arrives at i that offers the deviating price p. The consumer will purchase from i if her personal u_i from seeing the appearance of $i's$ product satisfies

$$\gamma u_i - p \geq \gamma u^* - p^* \geq 0,$$

where u_i will be realized only if the purchased product has quality $\xi_i = H$, which occurs with the expected probability γ; and the product will have zero value to the consumer if $\xi_i = L$. Hence, the demand for i from any visiting consumer, given that all other firms charge p^*, is

$$D(p, p^*) = 1 - F\left(\frac{\gamma u^* + p - p^*}{\gamma}\right),$$

which is independent of β_i, with $D(p^*, p^*) = 1 - F(u^*)$. The profit of i from any visiting consumer, $\pi(p, p^*) = pD(p, p^*)$, is maximized when p satisfies $\frac{\partial \pi(p,p^*)}{\partial p} = 0$. In equilibrium,

experience than for inspection goods, because for the latter consumers can detect and hence avoid the utility loss from consuming a low-quality product.

[28] Notice that for inspection goods, when visitng i, the consumer actually observes ξ_i and hence her belief about β_i becomes irrelevant.

[29] In the literature on experience goods, firms can sometimes signal their quality through price and other devices (e.g., Choi, 1998; Riordan, 1986; Shapiro, 1983; Wernerfelt, 1988). In the model here, given their qualities, firms are symmetric in all other aspects and price signaling is thus ruled out.

p is equal to p^*, and

$$p^* = \gamma\lambda\left(u^*\right). \tag{24}$$

Moreover, under the maintained condition (3), p^* uniquely exists, and it is lower when s is lower or u^* is higher (same as for inspection goods).

In equilibrium, each firm's profit is $\pi^* = \gamma\lambda\left(u^*\right)$. With a unit mass of firms and of consumers, industry profit, consumer surplus and total welfare are respectively:

$$\Pi^* = \gamma\lambda\left(u^*\right); \qquad V^* = \gamma\left[u^* - \lambda\left(u^*\right)\right]; \qquad W^* = \gamma u^*. \tag{25}$$

From (25), clearly V^* and W^* increase in γ, the average quality of firms in the market. The effects of γ on price (and profit) are less obvious, as we can see from (24):

$$\frac{dp^*}{d\gamma} = \lambda\left(u^*\right) + \gamma\lambda'\left(u^*\right)\frac{\partial u^*}{\partial\gamma},$$

where the first and the second terms on the RHS reflect, respectively, the positive (direct) demand effect and the negative (indirect) search effect on p^* from an increase in γ. A higher γ lowers the price elasticity of demand for given u^* and p:[30]

$$\eta = -\frac{\partial D\left(p, p^*\right)}{\partial p}\frac{p}{D} = \frac{p}{\gamma}\frac{1}{\lambda\left(\frac{\gamma u^* + p - p^*}{\gamma}\right)},$$

which positively impacts price; but it also increases the search reservation value u^* and negatively impacts p^* due to $\lambda'\left(u^*\right) \leq 0$. Under some regularity condition, the demand effect dominates so that $\frac{dp^*}{d\gamma} > 0$ (Chen et al., 2022).

Comparing (23) with (25), we see interesting similarities and differences in the properties of search equilibrium between inspection and experience goods. In particular: (1) Given γ, consumers search with the same reservation value (u^*) for inspection and experience goods, but profit, consumer surplus, and welfare are all lower for the latter. (2) A higher s reduces competition and leads to higher price in both cases. (3) As γ increases, equilibrium price is lower for inspection goods but *higher* for experience goods. Furthermore, a firm's

[30] When γ is higher, the quality-adjusted price $\frac{p}{\gamma}$ is lower and a marginal change in p is associated with less change in $\frac{p}{\gamma}$ and hence leads to less change in the quantity demanded.

profit increases in its quality (β) for inspection goods but is independent of its quality for experience goods. However, consumer surplus and welfare increase in γ for both inspection and experience goods.

To see the intuition behind the opposite results for the effects of γ on p^*, notice that with inspection goods, a higher average firm quality (γ) implies that consumers are more likely to find H from a search, with a higher expected search benefit. This boosts consumers' search incentive, as reflected by a higher u^*, which increases competition and leads to lower equilibrium price. Because consumers can observe product quality before purchase for inspection goods, an increase in γ has no effect on their demand for a firm. By contrast, for experience goods, product quality (ξ) is not observed before purchase, and thus a higher γ also increases a consumer's expected utility from the product and hence the demand for it. Consequently, while a higher γ similarly exerts a downward pressure on p^*—by raising u^*—as for inspection goods, it has the additional demand effect that, on balance, results in a higher equilibrium price.

5.2 Endogenous Quality: Investment and Quality Reputation

Chen et al (2022) use the **VHD** model to further study consumer search and competition when firm quality is determined endogenously through investment and firms can establish quality reputation.[31] Suppose that initially a unit mass of firms have $\beta = \beta^l$ but each firm can invest to improve β from β^l to β^h. The cost of the investment for each firm is x, which is a random draw from a continuous distribution $\Lambda(x)$ on $[0, \bar{x}]$. The market operates for two periods, with no discounting. In period 1, each firm first learns its realization of x and chooses whether to make the investment. Firms then simultaneously choose prices, after which a unit mass of consumers sequentially search firms, make possible purchases, and leave the market at the end of the period. In period 2, a unit mass of new consumers arrive

[31] This is related to other studies of consumer search with investment in product quality (e.g., Fishman and Levy, 2015; Moraga-González and Sun, forthcoming). Relatedly, Wolinsky (2005) and Moraga-González and Sun (2018) study consumer search models in which sellers exert costly efforts to create service plans. All of these only consider inspection goods.

and know the value of β_i for any firm i from the product reviews of period-1 consumers. That is, firms are able to establish quality reputation from their first-period sales. Active firms in the market again simultaneously choose prices, followed by consumers' sequential search and possible purchases.

If it is profitable for a firm with a higher x to make the quality investment, it must also be profitable for a firm with a lower x to do so. Thus, the market equilibrium has the property that, for some threshold θ, a firm will invest x to achieve high quality β^h if $x \leq \theta$ but will remain to have β^l without the investment if $x > \theta$. Suppose that $\bar{x}$ is high enough so that in equilibrium $\theta < \bar{x}$; i.e., some firms, whose realized values of x are sufficiently high, will not invest x.

For a given θ, the average firm quality in the market is

$$\gamma = \gamma(\theta) \equiv \Lambda(\theta)\beta^h + [1 - \Lambda(\theta)]\beta^l.$$

However, the equilibrium price and incentives to invest in quality differ for inspection and experience goods. Suppose that in equilibrium $\theta = \theta^\iota$ for inspection goods and $\theta = \theta^e$ for experience goods. Then, at the first-period equilibrium, all firms charge equilibrium price

$$p_1^* = \begin{cases} \lambda(u^\imath) & \text{for} \quad \text{inspection goods with } \gamma^\iota = \gamma(\theta^\iota) \\ \gamma^e \lambda(u^e) & \text{for} \quad \text{experience goods with } \gamma^e = \gamma(\theta^e) \end{cases},$$

where u^ι and u^e satisfy (21) respectively with $\gamma = \gamma^\iota$ and $\gamma = \gamma^e$.

In period 2, because from (23) and (25) each consumer's surplus increases in γ, consumers will only search firms with $\beta = \beta^h$. Therefore, only the β^h firms, whose mass is $\Lambda(\theta)$, will be active and have positive sales, and the equilibrium price is

$$p_2^* = \begin{cases} \lambda\left(u^h\right) & \text{for} \quad \text{inspection goods} \\ \beta^h \lambda\left(u^h\right) & \text{for} \quad \text{experience goods} \end{cases}.$$

For inspection goods, in equilibrium a firm will invest if and only if $x \leq \theta^\iota$, where the cutoff value θ^ι is determined by

$$\theta^\iota = \frac{\beta^h - \beta^l}{\gamma(\theta^\iota)} \lambda(u^\iota) + \frac{1}{\Lambda(\theta^\iota)} \lambda\left(u^h\right), \tag{26}$$

and $\theta^\iota \in (0, \bar{x})$ exists uniquely. Industry profit, consumer surplus, and total welfare for the two periods together are

$$\Pi^\iota = \lambda(u^\iota) + \lambda\left(u^h\right) - \int_0^{\theta^\iota} x d\Lambda(x); \qquad V^\iota = \phi(u^\iota) + \phi\left(u^h\right); \qquad W^I = u^i + u^h - \int_0^{\theta^\iota} x d\Lambda(x),$$

where $\phi(u) = u - \lambda(u)$.

An increase in s increases equilibrium prices and γ^ι, while its impact on consumer surplus under inspection goods is always negative (under some regularity condition):

$$\frac{\partial V^\iota}{\partial s} = \underbrace{\phi'(u^\iota)\frac{\partial u^\iota}{\partial s}}_{\text{search efficiency effect in period 1 } \leq 0} + \underbrace{\phi'\left(u^h\right)\frac{\partial u^h}{\partial s}}_{\text{search efficiency effect in period 2 } < 0} < 0.$$

Similarly, a higher s also lowers total welfare, due to not only the reduction in search efficiency but also an increase in total investment cost: the higher profit for being a β^h firm from an increase in s leads to more firms to incur x, while s/γ^ι still increases in s.

On the other hand, for experience goods, in equilibrium a firm will invest if and only if $x \leq \theta^e$, where the cutoff value θ^e uniquely satisfies

$$\theta^e \Lambda(\theta^e) = \beta^h \lambda\left(u^h\right). \tag{27}$$

Equilibrium consumer surplus and total welfare are

$$V^e = \gamma^e \phi(u^e) + \beta^h \phi\left(u^h\right); \qquad W^e = \gamma^e u^e + \beta^h u^h - \int_0^{\theta^e} x d\Lambda(x).$$

Same as for inspection goods, increases in search cost raise average firm quality, in addition to raising p_1^e and p_2^e. Intuitively, when s is higher, price is higher, and a firm has higher profit in period 2 for being a β^h firm. That is, the return to the reputation of being a high-quality firm is higher. This motivates more firms to invest in quality so that θ^e becomes higher, which boosts $\gamma(\theta^e)$ in period 1.

Hence, with endogenous firm quality and reputation, search cost continues to be a key indicator of competition intensity, with increases in s leading to less competition and high prices for both inspection and experience goods. However, under plausible conditions, consumer surplus and total welfare for experience goods, V^e and W^e, both initially *increase* in s, even though they eventually decrease. To understand this striking result, notice that the effect of a marginal increase in s on consumer surplus can be decomposed as follows:

$$\frac{\partial V^e}{\partial s} = \underbrace{\frac{\partial \gamma^e}{\partial s}\phi\left(u^e\right)}_{\text{firm quality effect} > 0} + \underbrace{\gamma^e \phi'\left(u^e\right)\frac{\partial u^e}{\partial s}}_{\text{search efficiency effect in period 1}} + \underbrace{\beta^h \phi'\left(u^h\right)\frac{\partial u^h}{\partial s}}_{\text{search efficiency effect in period 2} < 0} . \tag{28}$$

An increase in s raises the profit from being a β^h firm, motivating more firms to invest in quality and hence equilibrium average firm quality γ^e is higher in period 1. On the other hand, a higher s reduces u^e and u^h; that is, a higher search cost reduces search efficiency, which negatively impacts consumer surplus.

When search cost is low, price is low. Thus consumer surplus from the high-quality product (H), $\phi\left(u^e\right)$, is high, and the number of high quality firms (that incur x) is small. In such situations, although a marginal increase in s only raises prices slightly, the profit increase from being a β^h firm is large because of a big boost to its sales in period 2. Hence, a marginal increase in s leads to a large increase in the number of high-quality firms and in γ^e (i.e., $\frac{\partial \gamma^e}{\partial s}$ is high), which means that $\frac{\partial \gamma^e}{\partial s}\phi\left(u^e\right)$ is high, whereas the effect on search efficiency is more moderate. Thus the positive effect on firm quality dominates when s is small. On the other hand, when s is large, price is high. Thus $\frac{\partial \gamma^e}{\partial s}$ and $\phi\left(u^e\right)$ are relatively low, so that the negative search efficiency effect dominates.

The effect of search cost on total welfare for experience goods can be similarly analyzed. In addition to the average firm quality and search efficiency effects, as in the case of consumer surplus, for W^e there is the additional effect of investment cost: a higher search cost increases the total investment cost for β^e, because the higher profit for being a high-quality firm from an increase in s leads to more firms to invest in β^e. But when $s \to 0$, $\theta^e \to 0$, and thus the additional effect of investment cost vanishes so that W^e increases in s, similarly as for V^e. On the other hand, when s is large, the investment cost effect (alone) dominates the average firm quality effect, and W^e decreases in s, also similarly as for V^e.

In summary, for experience goods, consumer and total welfare can exhibit an inverted-U shape as s increases, in contrast to the result that they both monotonically decrease in s for inspection goods. For both types of goods, an increase in search cost leads to higher price and hence to higher returns for quality investment because only β^h firms make sales in period 2. However, consumers can avoid the loss from consuming product L for inspection but not for experience goods. Thus, the marginal benefit from increasing firm quality (γ) in period 1 due to a higher s is higher for experience goods. This explains why a higher s can be beneficial to consumers and total welfare for experience but not for inspection goods.

The welfare effects of search frictions for experience goods are in sharp contrast to the result in the existing search literature, where consumer and total welfare monotonically decrease as search cost rises.[32] Both endogenous firm quality and the experience nature of goods are important for the non-monotonic result for experience goods. If the average firm quality in the market (γ) is exogenously given, higher search costs would only have the negative effect of reducing search efficiency. When an increase in search cost has the additional effect of inducing a higher γ, it can have a positively effect on consumer and total welfare, and for experience goods this becomes the dominant force when search cost is sufficiently low. However, for inspection goods, even with endogenous product quality, both consumer and total welfare would rise as search cost falls.[33]

The results for consumer search and competition with experience goods are especially relevant for online markets where search cost is low and product quality is often difficult to observe before purchase. Online markets are thus more susceptible to low-quality sellers and low-quality products than traditional markets. The results suggest that this quality problem is unlikely to disappear even if search cost virtually vanishes. Rather, regulatory policies can play important roles in protecting consumers and increasing efficiency. One such policy is to impose minimum quality standards, when feasible, to prohibit the sale of low-quality products. Another possibility is to provide stronger consumer rights for product

[32] Taylor (2017) considers a model in which a seller can manipulate the browsing cost (search cost) of potential buyers. He shows that a higher browsing cost, by driving away less serious buyers and increasing the sales effort of the seller, can benefit consumers and increase welfare.

[33] This is consistent with the results in the existing literature, where a decrease in search cost boosts consumer surplus and welfare even when it leads to higher market price (e.g., Chen and Zhang, 2011; Bar-Isaac et al., 2012; Zhou, 2014; Moraga-González, et al., 2017; Choi, et al., 2018) or to lowers product quality (e.g., Fishman and Levy, 2015; Moraga-González and Sun, 2022).

return and other remedies to low quality. Product return is often costly to consumers for the time and effort involved, and it is not always feasible because a quality problem may not be detected promptly after purchase. But when it is feasible, product return can effectively change an experience good to an inspection good, improving efficiency. A related issue is how to design product liability to provide efficient incentives to invest in product quality, both for producers and for search platforms that can screen out low-quality sellers. These are interesting issues for future research.

6. CONCLUDING REMARKS

Random-quality models offer rich and novel insights on markets with consumer search. They shed light on the role of platforms in facilitating online advertising and search, as well as on how a platform's incentives may align with or diverge from efficiency. The research also shows that, in contrast to the common wisdom, decreases in entry costs can reduce consumer welfare in search markets, because the loss in search efficiency due to the entry of low-quality firms can outweigh the benefit from greater consumer choices. Moreover, contrary to the result for inspection goods, both consumer welfare and total welfare can fall as search cost decreases for experience goods. These findings deepen the understanding of how search markets function, with policy implications that can be especially relevant in digital markets.

Despite—or perhaps because of—the tremendous progresses it has made, the theory of industrial organization faces the challenge of identifying new directions in which to advance. Markets where costly consumer search interacts with strategic firm decisions have been a fruitful area of research in recent years. The random-quality approach is complementary to other modeling approaches and studies in this literature. As I discussed, many important issues in consumer search markets remain to be explored, some potentially with random-quality models, including: (i) platform design when sellers differ in quality, possibly under both vertical and horizontal differentiations; (ii) position auction and product liability for experience goods; (iii) competition and regulation in expert markets with consumer search;

(iv) search markets in which the information environment is determined endogenously by firms' data strategies and by data regulations; and (v) the joint design of data and antitrust policies in search markets.

Efforts may also be made to improve the modeling approach. For example, the random-quality models have assumed that each consumer's personal value u for a high-quality product is either identical or independent across firms. The true relationship may exhibit a more general dependence property, and it remains a challenge to develop a tractable model that allows any dependence relationships. Also, while binary product quality is a simplifying assumption that is often made in IO theory, it is nevertheless restrictive and can be relaxed in future research. For instance, product quality ξ could follow a continuous distribution, and firm quality may be modeled as a parameter that shifts the distribution. Such more general random-quality models could further research on search markets under quality uncertainty.

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