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 consumer search and competition in markets with 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 shall 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) match consumers' needs or (ii) be free of defects.[2] 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 $\xi = H$.[3] 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

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

[2] This assumes that each firm produces a single product. The approach can also be used to analyze markets with multiproduct firms, where a firm's different products vary in β.

[3] 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.

advertising with consumer search. In both papers, through the auctioning of ad positions, a platform acts as an information intermediary, directing consumers to (first) search more relevant sellers, which increases both search efficiency and expected output. However, as Chen and He (2011) also show, while the platform facilitates consumer search, it may lack the incentive to maximize search efficiency.[4] More recently, Anderson and Renault (2021) provide a more general analysis of position auctions with consumer search, bridging insights from this literature to the literature on ordered search (e.g., Armstrong et al. 2009). In a different direction, rather than exploring a monopoly platform's allocation of positions for competing single-product sellers, Nocke and Rey (2023) examine a random-quality model in which a monopoly firm offers multiple products that differ in β and consumers conduct within-firm search. They show that the firm often benefits from limiting the information available to consumers through a noisy positioning strategy.

(ii) Welfare effects of 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 increased entry from decreased entry cost 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 sellers before finding a match). When entry cost is sufficiently low, the latter effect is shown to dominate so that consumer welfare *increases* in entry cost. Interestingly, a similar tension is also present in Nocke and Rey (2023), where an expansion of the monopolist's product line offers more opportunities for a match but reduces the popularity among the products on offer and thus lowers the probability of

[4] The 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.

finding a match on any given inspection.

(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. They show that increases in average firm quality will lower equilibrium price for inspection goods but will raise it for experience goods. Furthermore, 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; but for experience goods they both *fall* as search cost decreases if it is already relatively low. 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 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 may be $i's$ 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 $\xi_i = H$.[5] 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) matches a consumer's need but a low-quality product (L) does not. For example, if a consumer wishes to purchase a certain pair of running shoes, H 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 L is defective (or is poorly made) and will have no value to consumers.[6] Firms may also differ in quality, with a higher-quality firm having a higher β, either because its product is more likely to be a match for any consumer (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.

[5] 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.

[6] 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.

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

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

under the standard assumption that we maintain:

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

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).[7]

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

[7] 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. 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.

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.[8] 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 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).[9] I will also discuss the use of this model in Chen and Zhang (2018) to investigate the welfare effects of entry in search markets. Moreover, in a variant of this model, Nocke and Rey (2023) analyze consumer search and steering by a multiproduct monopolist.

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),[10] and they can learn product quality

[8] 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.

[9] 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.

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

only after consumption if it is an experience good (Chen et al 2022).[11] 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 $F(u)$, conditional on a match), 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, 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) or within-firm search in a multiproduct firm that chooses the size of its product line (Nocke and Rey, 2023).

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., Armstrong et al. 2009; 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

[11] 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.

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.[12] 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. In what follows, we (re)name the N sellers as $S_1, ..., S_N$ so that $\beta_1 > \beta_2 > ... > \beta_N$, where 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.[13] The search

[12] Notice that even though u is the same across sellers for a given consumer, it is a random draw from distribution $F(u)$ and hence differs across consumers (which ensures positive surplus from searching and avoids market unraveling).

[13] Note that if the platform has access to data about each consumer's u, it could further improve outcomes

platform essentially acts as an information intermediary that directs consumer search.[14]

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.[15] 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.[16]

While the 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 is shown more generally by Eliaz and Spiegler (2011) in a **VHD** model, where the platform may have an incentive to set a relatively low price-per-click that encourages low-relevance

by sending consumers a binary signal such that they search if and only if u is weakly above p^m.

[14]This is related to the idea that advertising can serve as a device to coordinate consumer search (Bagwell and Ramey, 1994). In addition to the separating equilibrium that is the focus of the analysis, the model also has a partially pooling equilibrium that is of interest, where more relevant sellers bid the same amount to be placed on the platform in random order.

[15]The number of slots on the platform, n, is fixed exogenously in the paper. How many slots should the platform offer to maximize its revenue? It seems that a smaller n would intensify bidding but a larger n could also boost revenue through the extensive margin. Revenue may also depend on β. For example, if, $\beta_2 \approx \beta_1 \to 1$, it could be optimal for the platform to set $n = 1$ to obtain almost π^m. A general analysis of this issue is left for future research.

[16]Rhodes et al. (2021) show 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.

advertisers to enter the search pool, resulting in lower average quality of sellers on the platform.

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.[17]

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).

While the literature has mainly considered consumer search across competing single-

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

product firms on a platform, Nocke and Rey (2023) provide a novel analysis of consumer search within a multiproduct firm, which for our discussion can also be viewed as a platform. In their **VD** model with random quality, the firm chooses which available products to offer, their prices, and how to position them, while consumers with heterogeneous search costs conduct sequential search. Their analysis focuses on two equilibria, akin to the separating equilibrium and the partially pooling equilibrium in Chen and He (2011): (i) a pure positioning equilibrium, where the firm offers all available products at the monopoly price and fully reveals each product's match probability; and (ii) a random positioning equilibrium in which the firm offers the most popular products at monopoly price and assign the offered products to each slot with equal probability.

Compared to the pure positioning equilibrium, at the random positioning equilibrium consumers are unable to search efficiently and will obtain lower expected surplus, so that fewer of them engage in search; but those who start searching will keep doing so until finding a match, because a consumer's expected match probability rises after an inspection yields no match. Nocke and Rey (2023) show that the second effect at the *intensive* search margin can dominate the first effect at the *extensive* search margin, so that the firm prefers the random positioning equilibrium. Remarkably, inefficient noisy positioning arises even though the firm and consumers have the common interest of maximizing the probability of trade, without some of the motives that bias a platform (e.g., self-preferencing). As the authors point out, an exciting avenue for future work would be to study the extent to which competition between firms or platforms may act as a disciplining device to align firms' interests with those of consumers.

In many markets, products are "experience goods" for which the quality of a product may not be learned before purchase. Then, a platform may no longer be able to perform efficient sorting of sellers, because a low-quality seller could have lower cost and 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.[18] 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.[19]

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 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.

[18] 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).

[19] 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.

4. EFFECTS OF ENTRY IN SEARCH MARKETS

Chen and Zhang (2018) show that search cost drastically changes how entry affects consumer welfare.[20] 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.

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 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.[21] 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.

[20] 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.

[21] The discussion below focuses on situations where $n \geq 1$. Notice that given $k > 0$, there is a positive probability that $n = 0$, which occurs when the β values drawn by all N firms are low enough such that no one enters.

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

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

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

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

where

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

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:

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

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

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

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

and $t^* = t^*(k)$ 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

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

where Φ is a consumer's expected surplus from a matched seller whose product meets her need, and $M(t)$ 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 their 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 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.[22]

[22] Notice that search cost is crucial for the consumer welfare results of entry. As search cost approaches

Remarkably, with search frictions, product offerings can be excessive for consumer welfare not only under the free entry of single-product firms as in Chen and Zhang (2018), but also when a multiproduct monopolist chooses the size of its product line as in Nocke and Rey (2023). In fact, increasing product offerings have similar effects in the two papers, even though they deal with two very different market structures. In Nocke and Rey (2023)'s random positioning equilibrium, increasing the size of its product line by the firm offers more opportunities for a match but reduces the average popularity of the offered products and thus lowers the probability of finding a match on any given inspection. They show that the latter effect dominates for the marginal searcher, which implies that fewer consumers will visit the firm as the product line size expands, consistent with choice overload.

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. If $n = 1$, then the seller obviously charges the monopoly price; so $p_1 = p^m$. For $n \geq 2$, it can be shown that at any symmetric price equilibrium, each seller sets

$$p_n = \frac{[1 - F(a)]\, \varphi_n + \int_{p_n}^{a} [1 - \gamma + \gamma F(u)]^{n-1} f(u)\, du}{f(a)\, \varphi_n - \int_{p_n}^{a} [1 - \gamma + \gamma F(u)]^{n-1} f'(u)\, du}, \tag{17}$$

where $a(\gamma)$ is consumers' optimal reservation value and $a(\gamma)$ satisfies

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. A parallel analysis establishes that social welfare W can also exhibit an inverted-U shape as entry cost rises from zero.

$$\gamma \int_{a}^{\bar{u}} (u - a) f(u) \, du = s. \tag{18}$$

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. 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. Social welfare can also be an inverted-U shaped function of k.

While the most novel result from the analysis of Chen and Zhang (2018) is the effects of entry on consumer welfare, their finding about the effect of entry on social welfare also differs from those in several closely-related papers. Their **VHD** model is more closely related to Anderson and Renault (1999), who study an **HD** model with horizontally differentiated products and 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.

The results reviewed in this section 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.[23] 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 to it quality uncertainty, entry cost, and consumer search, so that a buyer can discover whether a car has a defect through inspection.[24] A high quality seller, whose car is less likely to be defective, then has a higher probability to result in a trade 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 low enough, 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

[23] 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.

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

variety and search quality effects of entry. Crucially, the search quality effect arises only because of the heterogeneity in sellers' quality and the asymmetric information about it: if all sellers have the same β or if consumers know each seller's β, then the entry of more firms would not reduce search efficiency, and hence increased entry due to a reduction in entry cost would always be good for consumers due to the beneficial variety effect.[25]

Digital technologies and the Internet have drastically reduced entry costs in many markets. However, as I have discussed, in the presence of search frictions, 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. For instance, although more app developers for iPhones and iPads 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 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.

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

[25] This suggests that online reviews, when they are accurate, can effectively guide consumers to directly search sellers according to their β's, restoring efficient entry.

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 $F(u)$. As I discuss below, 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 $\beta_i \in \{\beta^l, \beta^h\}$ 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^*,[26] 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 condition extends the optimal search rule for horizontally differentiated products (e.g., Wolinsky, 1986), which is

[26] 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.

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.[27] 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

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

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

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

which is independent of $\beta_i \in \{\beta^l, \beta^h\}$. The equilibrium output of firm i is $\frac{D(p^*, p^*)}{\gamma[1 - F(u^*)]} = \frac{\beta_i}{\gamma}$, and its equilibrium profit is $\pi(\beta_i) = \frac{\beta_i}{\gamma}\lambda(u^*)$. 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:

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

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.

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

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

[27] 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

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), the focus is still on a uniform-price equilibrium where all firms charge the same price p^*.[28] 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.

An analysis parallel to that under inspection goods establishes

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

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). 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 can be seen 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. Under some regularity condition, the demand effect dominates so that $\frac{dp^*}{d\gamma} > 0$.

[28] 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.

Comparing (23) with (25), we see interesting similarities and differences in the properties of search equilibrium between inspection and experience goods. In particular: (i) 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. (ii) A higher s reduces competition and leads to higher price in both cases. (iii) As γ increases, equilibrium price is lower for inspection goods but *higher* for experience goods. Furthermore, a firm's 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.

One may wonder what happens if consumers observe whether they have a match (i.e., they observe ξ) but only learn u after purchase. In this case, a consumer's matched products all have the same expected value, and firms will behave as if they are competing for a homogeneous product. The Diamond equilibrium then prevails: consumers will all search once (which is free), and firms will charge a price that is equal to the expected value of u, leaving zero surplus to all consumers even for those whose search yields a match.[29] Therefore, observing u but not ξ is better for consumers than observing ξ but not u during

[29] A similar hold-up problem also arises in Rhodes (2015)'s model of multiproduct retailing, where the problem is alleviated when a firm offers a large product range or advertises a low price on one product.

search, because effective competition is preserved under heterogeneous u.

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.[30] 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 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.

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

[30] 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.

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 higher 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:

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

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), $\phi(u^e)$, 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 $\frac{\partial \gamma^e}{\partial s}\phi(u^e)$ 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 $\phi(u^e)$ 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, 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.[31]

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

[31] Instead of investing in β, firms may invest to increase u by shifting $F(u)$. Then, the consumer benefit from the investment may no longer be higher for experience than for inspection goods, because conditional on $\xi = L$, in both cases a consumer would receive zero value from the product. Hence, the nature of investment could matter for the possible different welfare effects of search cost for inspection and experience goods.

[32] Notable exceptions: When a seller can manipulate the browsing cost of potential buyers, Taylor (2017) shows that a higher browsing cost can benefit consumers by driving away less serious buyers while increasing the sales effort of the seller; while with endogenous market structure, Rhodes and Zhou (2019) find that lower search frictions can lead to a segmented market structure with higher prices and lower consumer welfare.

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 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

[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 lower product quality (e.g., Fishman and Levy, 2015; Moraga-González and Sun, 2022).

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. Moreover, there may be competition by multiproduct firms that differ in product quality both within and across firms. Such more general random-quality models could further research on search markets under quality uncertainty.

REFERENCES

Akerlof, G. (1970). 'The market for 'lemons': quality uncertainty and the market mechanism' *Quarterly Journal of Economics*, Vol. 84, pp. 488–500.

Anderson, S. and Renault, R. (1999). "Pricing, Product Diversity, and Search Costs: A Bertrand-Chamberlin-Diamond Model." *RAND Journal of Economics,* Vol. 30 , pp. 719–735.

Anderson, S. and Renault, R. (2021). "Search Direction: Position Externalities and Position Auction Bias." working paper.

Armstrong, M., Vickers, J., and Zhou, J. (2009). "Prominence and Consumer Search." *RAND Journal of Economics*, Vol. 40, No. 2, pp. 209–233.

Athey, S. and Ellison, G. (2011). "Position Auctions with Consumer Search." *Quarterly Journal of Economics*, Vol. 126, pp. 1213–1270.

Bagwell, K., and G. Ramey (1994): "Coordination Economies, Advertising, and Search Behavior in Retail Markets," *American Economic Review*, 84(3), 498–517.

Bar-Isaac, H, Caruana, G., and Cuñat, V. (2012). "Search, Design, and Market Structure." *American Economic Review*, Vol. 102(2), pp. 1140-1160.

Burguet, R., R. Caminal, M. Ellman (2015). "In Google We Trust?" *International Journal of Industrial Organization*, 39: 44–55.

Cao, Y., Y. Chen, Y. Ding and T. Zhang (2022). "Consumer Search and Competition in Expert Markets." Working paper..

Chen, Y. and C. He (2011). "Paid Placement: Advertising and Search on the Internet." *Economic Journal,* Vol.121, pp. F309-28.

Chen, Y. and T. Zhang (2011). "Equilibrium Price Dispersion with Heterogeneous Searchers." *International Journal of Industrial Organization*, Vol. 29, pp. 645-654.

Chen, Y. and T. Zhang (2017). "Intermediaries and Consumer Search." *International Journal of Industrial Organization,* EARIE Special Issue.

Chen, Y. and T. Zhang (2018). "Entry and Welfare in Search Markets." *Economic Journal,* Vol. 128 (608), 55-88.

Chen, Y., Z. Li and T. Zhang (2022). "Experience Goods and Consumer Search." *American Economic Journals: Microeconomics*.

Choi, J.P. (1998). "Brand Extension as Informational Leverage." *Review of Economic Studies*, Vol. 65 (4), pp. 655-669.

Choi, M., Y. Dai and K. Kim (2018). "Consumer Search and Price Competition." *Econometrica*, Vol. 86 (4), pp. 1257–1281.

de Cornière, A. and Taylor, G. (2014) "Integration and Search Engine Bias." *RAND Journal of Economics*, Vol. 45, pp. 576–597.

Dogan, M. and J. Hu. (2022) "Consumer Search and Optimal Information." *RAND Journal of Economics,* 53: 386-403.

Dranove, D. and Satterhwaite, M. (1992). 'Monopolistic competition when price and quality are imperfectly observable' *RAND Journal of Economics*, Vol. 23, pp. 518-534.

Edelman, B., M. Ostrovsky, and M. Schwarz (2007). "Internet Advertising and the Generalized Second-Price Auction: Selling Billions of Dollars Worth of Keywords." *American Economic Review* 97 (1): 242-59.

Eliaz, K. and Spiegler, R. (2011). "A Simple Model of Search Engine Pricing." *Economic Journal,* Vol.121, pp F329-39.

Fishman, A. and N. Levy (2015). "Search costs and investment in quality." *Journal of Industrial Economics*, Vol. 63 (4), pp. 625-641.

Gomes, Renato. (2014). "Optimal auction design in two-sided markets", *RAND Journal of Economics*,45: 248-272.

Haan, M. A. and Moraga-González, J. L. (2011). "Advertising for Attention in a Consumer Search Model." *Economic Journal,* Vol. 121, pp. 552–579.

Janssen, M. and T. Ke (2020). "Searching for service." *American Economic Journal: Microeconomics, 12(1): 188-219*.

Mankiw, G. and Whinston, M. (1986). "Free entry and social inefficiency" *RAND Journal of Economics*, Vol. 17, pp. 48–58.

Moraga-González, J. L, Z. Sandor, and M. Wildenbeest (2017). Prices and Heterogeneous Search Costs. *RAND Journal of Economics*, Vol. 48, pp. 125-146.

Moraga-González, J. L, and Y. Sun (2018). "Consumer Search Costs and the Provision of Service Quality." working paper.

Moraga-González, J. L., & Sun, Y. (2022). "Product Quality and Consumer Search." *American Economic Journal: Microeconomics*, forthcoming.

Nocke, V. and P. Rey. (2023). "Consumer Search, Steering and Choice Overload." *Journal of Political Economy*, forthcoming.

Rhodes, A. (2011). "Can Prominence Matter Even in an Almost Frictionless Market?" *Economic Journal*, 121: F297–F308.

Rhodes, A. (2015). "Multiproduct Retailing." *Review of Economic Studies*, 82: 360 - 390, 2015.

Rhodes, A. and J. Zhou (2019). "Consumer Search and Retail Market Structure." *Management Science,* 65: 2607-2623.

Rhodes, A., M. Watanabe and J. Zhou (2021). "Multiproduct Intermediaries." *Journal of Political Economy*, 129: 421-464.

Riordan, M. H. (1986). "Monopolistic Competition with Experience Goods." *Quarterly Journal of Economics*, 101(2): pp. 265–279.

Shapiro, C. (1982). "Consumer Information, Product Quality, and Seller Reputation." *Bell Journal of Economics*, Vol. 13, pp. 20–35.

Shapiro, C. (1983). "Premiums for High Quality Products as Returns to Reputations." *Quarterly Journal of Economics*, 98: 659-680.

Stigler, G. (1961). "The Economics of Information." *Journal of Political Economy*, Vol. 69, pp. 213-225.

Stahl, D. (1989). "Oligopolistic Pricing with Sequential Consumer Search." *American Economic Review*, Vol. 79, pp. 700-712.

Taylor, G. (2017). "Raising Search Costs to Deter Window Shopping Can Increase Profits and Welfare." *RAND Journal of Economics,* Vol. 48, pp. 387-408.

Teh, Tat-How and J. Wright (2022). "Intermediation and Steering: Competition in Prices and Commissions." *American Economic Journal: Microeconomics*, 2022, Vol. 14(2), 281-321.

Varian, H. (1980). "A Model of Sales." *American Economic Review*," 70: 651-659.

Varian, H. (2007). "Position Auction." *International Journal of Industrial Organization*, 25: 1163-1178.

Wernerfelt, B. (1988). "Umbrella Branding as a Signal of New Product Quality: An Example of Signaling by Posting a Bond", *RAND Journal of Economics*, 19: 458-66.

White, A. (2013). "Search Engines: Left Side Quality Versus Right Side Profits." *International Journal of Industrial Organization*, 31: 690-701.

Wolinsky, A. (1983). 'Prices as signals of product quality' *Review of Economics Studies*, Vol. 50, pp. 647-658.

Wolinsky, A. (1986). "True Monopolistic Competition as a Result of Imperfect Information." *Quarterly Journal of Economics,* Vol. 101(3), pp. 493–511.

Wolinsky, A. (2005). "Procurement via Sequential Search." *Journal of Political Economy,* Vol. 113(4), pp. 785–810.

Zhou, J. (2014). "Multiproduct search and the joint search effect." *American Economic Review*, 104: 2918-39.

Zhou, J. (2022). "Improved Information in Search Markets." working paper.