# Categorization and Search

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## 1 Introduction

In many markets consumers do not directly observe products' characteristics or prices. There are two distinct paradigms in the literature that analyze such markets: search models and information disclosure models. In the search literature it is assumed that consumers actively search to become better informed by sampling different sellers to find products compatible with their preferences. Firms, by contrast, are anonymous and play a passive role with respect to consumers' search behavior. They may determine their own product characteristics (including prices), but they are unable to reach out to their customers and can only sell to those consumers by whom they are sampled (for a survey of search models see Baye, Morgan and Scholten, 2006)[1].

In the information disclosure literature, it is the firms who are active. Firms can directly communicate relevant product information to consumers by advertising (see

[1]For search models with differentiated products see Wolinsky, 1986, and Anderson and Renault, 1999, in which consumers actively and randomly search for a firm which matches their taste,

the survey by Bagwell, 2007) or any other information disclosure technique (see the survey by Milgrom, 2008) and thus affect how the latter perceive their products. But information disclosure can only be effective if firms are identifiable to consumers, not if they are anonymous as it typically assumed in the search literature. Thus these two strands of research have progressed on separate tracks.

The classical search paradigm is designed to capture the simple situation in which consumers physically visit different stores before settling on a store or brand which best matches her taste and budget. But, in the internet era, actual consumer search is cheaper, more sophisticated and more efficient. So far the focus of the research has been on the effect of the internet on reducing search cost (e.g. Janssen and moraga (2004). But modern consumers can use online sources that list sellers under various categories to narrow down the list of potential sellers from which to further refine their search. Thus the internet has not merely reduced consumers' search costs, but has also changed the way that consumers search. Firms respond to these more sophisticated search procedures and more effectively target the customers they wish to attract, by strategically choosing the sites and product categories under which they are listed.

The focus of this paper is on the relationship between the category architecture and the type of information which may be credibly disclosed by firms to searching consumers. In our setting both firms and consumers actively try to overcome informational asymmetries: firms by choosing a specific category to list their product, and consumers by choosing a category to search. The firms' category choice can be viewed as a form of active information disclosure. However, in contrast to conventional information disclosure, in our setting the information which actually reaches consumers depends on the latter's active participation. That is, the information which is disclosed by firms' choice of category is only revealed to consumers who actually choose to search in that category.

We consider a setting in which each firm produces one type of product and products are differentiated both horizontally and vertically. There are two types of products, $A$ and $B$, and each product is available in low or high quality. Consumers differ with respect to their preferences between the product types but they all prefer high quality over low quality. Consumers know the distribution of firm characteristics but must

incur search costs to find specific product attributes. While in the standard search setup consumers sample the entire population of firms, here we assume that there are different categories of products in which consumers may search. The categories may be in terms of firms' horizontal characteristics only, vertical characteristics only, or both types of characteristics. Firms do not control the categorization structure and are unable to create new categories but can only decide in which categories to be listed. The availability of exogenous product categories may enable firms to direct consumer search and promote more efficient match between products and consumers.

We analyze different category architectures. First we consider the case in which only horizontal categories, $A$, $B$ and $AB$, are available, where category $AB$ provides no explicit information about product type. Given this category structure firms decide the category in which to list their products while consumers choose a category in which to search. While it is simple to show that such horizontal categorization gives rise to an equilibrium that provides perfect information regarding the firms' horizontal characteristics, the paper shows that there also exists an equilibrium in which only the low-quality firms list according to product type, while high-quality firms list in the anonymous $AB$ category.[2] In this equilibrium, a firm implicitly discloses that it is of high quality by not disclosing its product type. Thus in the former equilibrium consumers have perfect product type information, while in the latter they have perfect quality information.

We then consider the case in which only vertical (quality) categories are available and show that there are no equilibria in which firms fully reveal their quality if vertical categories are not *verifiable* - that is, if firms are able to list under any category they wish, even if their product doesn't match the category description. Thus, in our setting, firms are able to reveal their quality when the available categories describe only horizontal characteristics but not when the available categories explicitly refer to quality.[3] We also show that when there are both vertical and horizontal categories (but the latter ones are not verifiable), firms cannot reveal more information than when there are only

[2] This equilibrium exists only for appropriate parameters.

[3] When products are unverifiable one can clearly replicate the equilibrium with horizontal categories by renaming the categories.

horizontal categories are available.

In Section 5 we extend the analysis by considering a market where firms can choose whether to enter the market. While entry is free we assume that there are entry costs which are higher for the high quality firms. This setup allows us to examine how the category structure feeds back on and determines the equilibrium distribution of product qualities. Focusing on horizontal categorization we show that when search costs are relatively small both the quality revealing equilibrium and the product-type revealing equilibrium exist but the quality revealing equilibrium induce a higher fraction of high quality firms and a greater consumers' surplus.

The paper is related to the literature on informative advertising in which the focus is the process by which firms transmit costly information about prices (e.g., Butters, 1977) or match quality (e.g., Grossman and Shapiro, 1984, and Meurer and Stahl, 1994) to consumers in the presence of informational frictions. In most of this literature it is the firms who actively advertise but consumers do not search. Papers which combine both channels of information - consumer search and advertising by firms - include Robert and Stahl (1993) and Janssen and Non (2008), in which some consumers become informed by actively searching and others are passively informed by advertising.[4]

Although the settings are very different, the feature of our model that consumer search is not random is also shared with the recent literature on ordered search and search with prominence (see Arbatskaya, 2007, Armstrong, Vickers and Zhou, 2009, Armstrong and Zhou, 2011, Zhou, 2011, and Hann and Moraga-Gonzalez, 2012) in which the pattern of consumer search follows an exogenously determined order. Prominence can be incorporated into our search with categorization setting by assuming that firms may have different prominence in different categories and thus their category choice may depend also on their prominence in the different categories and not just on the categories' signalling value.

It is interesting to note that in a different monopoly setting, Mayzlin and Shin (2009)

[4] Anderson and Renaut (2005) also consider a setting in which consumers become informed through a combination of search and advertising - consumers decide whether or not to incur the cost of "searching" a monopoly firm based on the ad they recive from the firm beforehand. Also, de Corniere (2012) develops a model of targeted advertising in which consumers must actively search for targeted ads.

derive an equilibrium similar to our quality disclosure equilibrium. In their model, the product has two vertical attributes. The firm is able to disclose only one attribute at most but consumers can learn about both attributes through costly search. They show that a signalling equilibrium can exist where the high quality firm signals that it is high-quality in the second dimension by not disclosing its type in the first dimension.

# 2 A Model of Search with Categories

Consider a market with a continuum of firms whose measure is normalized to 1. Firms' products are differentiated both horizontally and vertically. There are two product types, $A$ and $B$ (e.g., $A$ is Japanese food and $B$ is Chinese food). Half of the firms produce product $A$ and the other half produce product $B$. In each group of firms, a fraction $\alpha$ produce a high-quality product (denoted $H$), and a fraction $1-\alpha$ produce a low-quality product (denoted $L$). A firm's type is denoted as $t_f \in T_f = \{AH, AL, BH, BL\}$, where, for instance, $AH$ indicates product $A$ of high quality. We assume that firms have constant marginal cost, which is assumed to be zero. In the basic model we keep the number of firms of each quality type fixed. In section 5 we consider free entry of firms and endogenize the fraction of firms of each quality type.

There is a continuum of consumers of measure $m$. Consumer have heterogenous preferences with respect to the product type ($A$ or $B$) and with respect to the product quality ($H$ or $L$). Specifically, $A$ and $B$ are located at the two ends 0 and 1 of a Hotelling line of length one. Consumers are distributed uniformly along this line, and a consumer's location is denoted by $x \in [0,1]$. Let $\gamma$ be the Hotelling unit "transportation cost". All consumers prefer high quality to low quality but differ with respect to their valuation for quality, which is indexed by $q \in [0,1]$, which is also uniformly distributed. Thus, a consumer's type is denoted by $t_c = (x,q) \in T_c \equiv [0,1]^2$. The valuation of a type $(x,q)$ consumer for the low-quality $A$ product and the high-quality $A$ product are respectively,

$$U_{AL}(x,q) = v - \gamma x \quad \text{and} \quad U_{AH}(x,q) = v + q - \gamma x \ .$$

Similarly, her valuations for the low-quality $B$ product and the high-quality $B$ product

are respectively,

$$U_{BL}(x,q) = v - \gamma(1-x) \text{ and } U_{BH}(x,q) = v + q - \gamma(1-x) \ .$$

We assume that $v$ is large enough that the market is fully covered.

In our setting the products differ from one another along two dimensions: product type and quality. The first one represents horizontal variation as some people prefer product $A$ while others prefer product $B$. The second one represents a vertical variation as all consumers prefer $H$ over $L$.[5] We do not formally consider price competition in our model. But we can view prices as a special case of vertical differentiation. That is, the $H$ and $L$ differentiation can represent two levels of prices and obviously one can extend our setup to include several price levels.[6]

We assume that e*x ante* consumers do not know the product type nor the quality type of any firm, but they can learn both through a sequential search process. Whenever a consumer investigates a firm, she learns its type. Following convention, we assume that it is costless to investigate the first firm but after that it costs $s$ to investigate each additional firm. We further assume that search is not too costly such that $s < \min\{\frac{1}{2}, \frac{\gamma}{2}\}$. After each search, a consumer learns the firm's type and then decides whether to buy the product or to continue to search. A consumer's surplus from buying product $i$ of quality $j$, where $i = A, B$ and $j = L, H$, after searching $n$ times is $U_{ij}(x,q) - (n-1)s$.[7]

In conventional search models, there are no product categories (or, equivalently, there is only one category), and consumers search by sampling firms randomly as firms are *ex ante* identical. Here we depart from this and implicitly suppose that there is an information intermediary (e.g., a search website such as Yelp.com) that provides different categories of products. The set of all possible categories is

$$C^A \equiv \{A, B, AB, AH, BH, AL, BL, H, L, HL\} \ .$$

[5]More broadly speaking, the vertical dimension does not have to be quality. It can be two different colors, say, red and blue, provided that all people prefer one color over the other.

[6]Note also that in most web based categorization prices also appear as discrete categories (for example \$ and \$\$ symbols for restaurants etc).

[7]Information frictions and costly search are necessary for studying categorization. If information is perfect or search is costless, whether there is categorization or not does not make any difference.

A *category structure* $C \subseteq C^A$ specifies the available categories. For example if there are categories only with respect to the horizontal dimension then $C = \{A, B, AB\}$. When more than one category exists, each firm needs to choose in which category it will be listed and consumers decide in which category to search. Once a consumer chooses a category, she can inspect as many firms in that category as she likes, where firms within the category are sampled in a random order. Unless otherwise stated, we will assume that a firm can only list itself under one category and that consumers can only search within one category. (See section 6 for a discussion of the possibility that a firm can list under multiple categories.) Note, however, that since we assume a continuum of firms, a consumer will never search more than one category even if she can - if it was previously optimal to search in a specific category, it remains optimal to search that category after having sampled a finite number of firms in that category.[8]

A potentially important distinction is between *verifiable categories* and *non-verifiable categories*. When categories are verifiable firms cannot join a category that is different from the type of product they sell. This might be because the information intermediary can verify the type of product that firms produce and can make sure that a firm's product actually matches the category in which it is listed.[9] For example, if categories are verifiable and $C = \{A, B, AB\}$, then firms that produce product $A$ may only be listed under categories $A$ or $AB$ and firms which produce product $B$ may only be listed under categories $B$ or $AB$. Similarly, if $C = \{H, L\}$ and categories are verifiable, all high quality firms must choose $H$ while low quality firms must choose $L$. By contrast, if categories are not verifiable, then a firm can list itself in any category.

Formally, we define "*a search problem with categories*" as a search problem with a given set of categories $C$ such that (i) the strategy of a firm is its choice of category $S_f : T_f \to C$ in which it is listed; (ii) all consumers have the same beliefs about the distribution of product types in each category, denoted as $B(C)$; (iii) given these beliefs consumers choose the category in which to search and their acceptance set in that

[8] In a model with a finite number of firms the search strategy would need to specify a sequence of categories which consumers search through.

[9] Or consumers' behavior is such that whenever they observe such a contradiction they don't buy from such firms.

category, i.e., the set of product types that they are willing to accept in that category without further search. Formally, consumers' strategy set is $S_c : T_c \times B(C) \rightarrow C \times AC$ where $AC$ is consumer's acceptance set (which isa subset of the product types in the chosen category).

Denote by $\pi_{t_f}(s_{t_f} \mid C, s_c, s_f)$ the profit of a firm of type $t_f$ when its category choice strategy is $s_{t_f}$ given the category structure $C$ and the strategies of all the other firms and consumers ($s_f$ and $s_c$ respectively). Denote by $u_{t_c}(s_{t_c} \mid C, B(C))$ the expected surplus of a consumer of type $t_c$ when she chooses strategy $s_{t_c}$ given her beliefs about the distribution of product types in each category.

**Definition 1** *For a given category structure $C$ a search with categories equilibrium is a triple $\{s_c^*, s_f^*, B^*(C)\}$ such that:*

- The consumers' search strategy $s_c^*$ is optimal given their beliefs $B^*(C)$.
- The consumers' beliefs $B^*(C)$ are consistent with the firms' strategies $s_f^*$.
- For each type of firm, $s_{t_f}^*$ maximizes their payoffs given the consumers' strategies $s_c^*$ and other firms' strategies $s_{t_f}^*$ .

Note that the above definition applies whether or not firms can list in more than one category and whether or not categories are verifiable. If firms are able to list in more than one category, a firms' strategy is a choice of a subset of $C$. When categories are verifiable, verifiability constrains firms to list only in categories which match their type.

For any category structure $C$ there are sets of strategies $s_f$ under which some categories are empty.

**Definition 2** *An "empty category" is a category in which the measure of firms is zero.*

The specification of consumer search behavior when there are empty categories is an important ingredient of the consumers' search strategy. When considering a putative equilibrium with one or more empty categories, it is necessary to specify consumers' beliefs and behavior when a firm deviates and chooses to list under an empty category

(which is "supposed" to be empty). We will adopt the following simple behavioral rule:[10]

**Assumption 1** *Consumers do not search empty categories.*

Under this assumption, a firm which lists in an empty category has no customers. Therefore, if in some equilibrium one or more categories are empty, it can never be profitable for a firm to deviate by listing itself under such a category. Note that since we assume continuum of firms a deviation of a firm to an empty category is not going to change the fact that there is still a measure zero of firms in this category.

# 3 Horizontal Categorization

We first consider the case in which there are only horizontal categories, that is $C = \{A, B, AB\}$. In this case there are several possible equilibria. The first possibility is that categorization provides no information about product type or quality. This occurs if all firms list under the same category, say $AB$. This case is essentially equivalent to a setting without any categories. A second possibility is that categories provide complete information about product type. That is, all type $A$ firms list under one subset of categories while all type $B$ firms list under a disjoint subset of categories. In this case consumers can perfectly infer a firm's product type from the category under which it is listed, but no quality information is revealed at all. The third possibility is that low-quality firms and high-quality firms choose to list under different categories so that even if the horizontal categories do not *explicitly* provide quality information, consumers are able to infer it from firms' category choices. For expositional convenience only, in the remainder of this section we assume that horizontal categories are verifiable, though this assumption is not crucial for our analysis. When horizontal categories are not verifiable, corresponding to the equilibria derived below there also exist identical equilibria in which the names of the categories are permutated.

[10] An alternative approach would be to follow the signalling literature and specify as part of the equilibrium construction consumers' off-equilibrium beliefs if they observe a deviation to an empty category.

## 3.1 Horizontal categorization reveals quality information

There are two possible ways in which a horizontal categorization $C = \{A, B, AB\}$ may provide information about the vertical attribute. The first one is when the low-quality firms, either of type $A$ or type $B$, list in category $AB$ while firms that produce the high-quality $i$ product list in category $i$, $i = A, B$. A second possibility is that high-quality firms of either type list in category $AB$ while low-quality firms of type $i$ list in category $i$. The second case is illustrated in Figure 1 below.

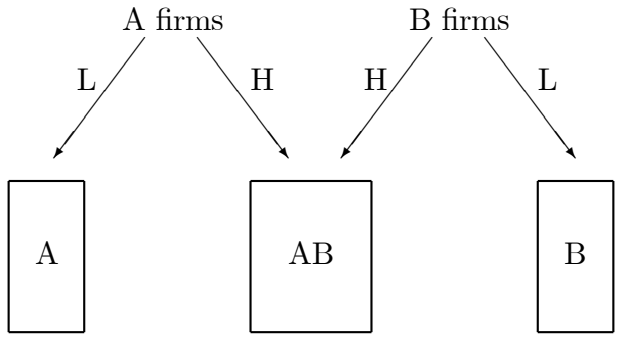


Figure 1: Horizontal categorization reveals quality information

As shown in the following result, the first type of equilibrium does not exist but the second exists under certain conditions.

**Proposition 1** *(i) There is no equilibrium in which all low-quality firms list in $AB$, and high-quality $i$ firms list in category $i$, $i = A, B$.*
*(ii) (**Quality revealing equilibrium**) When*

$$\frac{2 + s/\gamma}{2(1 - s/\gamma)} \frac{1 - s + s^2/\gamma}{1 - s + 2s/\gamma} \leq \frac{\alpha}{1 - \alpha} \leq \frac{1 - s + s^2/\gamma}{s - s^2/\gamma}, \tag{1}$$

*there is an equilibrium in which all high-quality firms list in category $AB$, all low-quality $i$ firms list in category $i$, $i = A, B$, and consumers follow the search strategy described in Figure 2 below.*

Before proving the proposition, we first explain Figure 2. Consumers who do not care too much about quality (i.e., with $q < s$) but care about product type search category $A$ or $B$, depending on their locations, even if they expect to get a low-quality product for sure. These consumers distribute on the regions of "search $A$" and "search

$B$" in Figure 2. ($v - \gamma x$ and $v - \gamma(1-x)$ are the corresponding surplus in each region, respectively, since these consumers will buy the first product they sample and the first search is costless.) Consumers who care about both quality and product type search category $AB$ (because all products in that category are of high quality) and, within that category, search until they find the right product type. They distribute on the two regions of "actively search $AB$". These consumers search twice on average and their expected search cost is thus $s$. Their surplus is indicated in each region. Finally, consumers who do not care too much about product type search category $AB$ for high-quality products, but accept the first product they encounter, whether it is type $A$ or $B$. They distribute on the central region of "search $AB$".

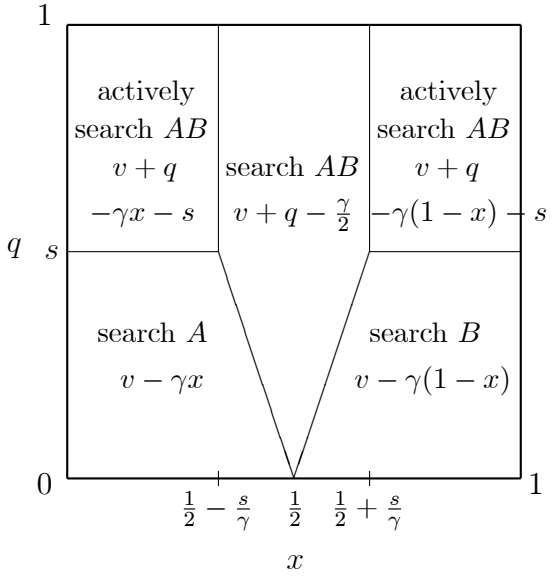


Figure 2: Pattern of demand when horizontal categories reveal quality information

**Proof.** (i) If there were such an equilibrium, consumers with $x < \frac{1}{2}$ would optimally search in category $A$ (which gives them their preferred product type and high quality without search) while consumers with $x > \frac{1}{2}$ would optimally search in category $B$. As a result, the low-quality firms in category $AB$ would have no customers and thus earn zero profits. Now consider a low-quality firm of type $i$ that deviates to category $i$. Consumers who have a sufficiently low valuation for quality (i.e., those with a sufficiently low $q$) and search in that category would buy this low-quality product without further

search if it is encountered first. Thus this deviation would be profitable. This is a contradiction.

(ii) Suppose that indeed in equilibrium high-quality firms list in $AB$, low-quality $i$ firms list in category $i$ and consumers believe that firms list in this manner. Consider a consumer at $x < \frac{1}{2}$ (the case with $x > \frac{1}{2}$ is symmetric). She has three relevant search options. The first is to search category $A$ and get a low-quality $A$ product; the second is to search category $AB$ and buy the first sampled product; and the third option is to search category $AB$ until she finds an $AH$ product. This consumer's optimal search behavior is derived by comparing these three options. (Notice that searching category $B$ is dominated by searching category $A$ for a consumer at $x < \frac{1}{2}$.)

If a consumer searches category $A$ then, given her belief about the distribution of qualities she will buy the first product she samples. Thus her expected surplus will be $v - \gamma x$. Suppose the consumer searches category $AB$. If she does not actively search in $AB$ and buys the first product she samples, her expected surplus will be

$$\frac{1}{2}(v + q - \gamma x) + \frac{1}{2}(v + q - \gamma(1 - x)) = v + q - \frac{\gamma}{2} \ .$$

If she searches sequentially until finding an $A$ product then she needs to sample two products on average. Since the first sampling is costless, the (expected) search cost is only $s$. Consequently her expected surplus will be

$$v + q - \gamma x - s \ .$$

By comparing the above three options, one can check that given our assumption that $s < \min\{\frac{1}{2}, \frac{\gamma}{2}\}$ the optimal consumer search behavior is described as in Figure 2.

Now we check that, given the consumer's choice behavior, no firm has an incentive to deviate from its listing choice. Consider an $AH$ firm first. In the proposed equilibrium, its demand is

$$Q_H \equiv \left(1 - s + \frac{s^2}{\gamma}\right) \frac{m}{\alpha} \ , \tag{2}$$

where $(1 - s + \frac{s^2}{\gamma})m$ is the measure of consumers who chooses category $AB$, and $\alpha$ is the measure of high-quality firms. Notice that due to symmetry, an $AH$ firm has the same demand as a $BH$ firm, and thus each high-quality firm's demand is simply the

number of consumers that search in the $AB$ category divided by the number of firms listing in this category.

Suppose then an $AH$ firm deviates and choose to list in category $A$. Then the consumers who search this category and encounter it will buy its product without further search. So this $AH$ firm's demand will be identical to any $AL$ firm's demand in category $A$. To calculate this demand notice that in the proposed equilibrium, $\frac{s}{2}(1-\frac{s}{\gamma})m$ consumers choose to search in category $A$, and there are $\frac{1-\alpha}{2}$ $AL$ firms in this category. Therefore,

$$Q_L \equiv \frac{\frac{s}{2}(1-\frac{s}{\gamma})}{\frac{1-\alpha}{2}}m = \left(s - \frac{s^2}{\gamma}\right)\frac{m}{1-\alpha} \ . \tag{3}$$

Consequently, a high-quality firm has no incentive to deviate and advertise in category $A$ or $B$ if

$$Q_L \leq Q_H \ . \tag{4}$$

Now turn to an $AL$ type firm. Its equilibrium demand is $Q_L$ in (3). Suppose now that this firm deviates and lists in category $AB$. To calculate the deviation demand we need to figure out how a consumer who chooses to search in category $AB$ will behave if she encounters this deviation firm. We only need to consider those consumers on the left region of "actively search $AB$" and the region of "search $AB$" on Figure 2. (Those consumers on the right region of "actively search $AB$" will never buy from this $AL$ firm since they do not even buy from an $AH$ firm.)

If a consumer buys from this $AL$ firm, her surplus is $v-\gamma x$. If she searches once more and buys at the next firm (which must produce a high-quality product), her expected surplus is $v+q-\frac{\gamma}{2}-s$. If she searches until finding a $AH$ product, her expected surplus is $v+q-\gamma x-2s$. (Notice that the consumer needs to search twice on average in order to find an $AH$ product.) The consumer's optimal behavior can be derived by comparing these three options. Given the assumption of $s<\frac{1}{2}$, the consumer will buy from this deviation firm if she locates on $[0,\frac{1}{2}-\frac{s}{\gamma}]\times[s,2s]$ or on the region of "search $AB$" below the line $q=\gamma(\frac{1}{2}-x)+s$. One can verify that the area of this whole region is $\frac{s}{2}+\frac{s^2}{4\gamma}$.

Notice that for an $AH$ product, those consumers on the left region of "actively search $AB$" or on the region of "search $AB$" will buy it immediately once they sample

it. The area of the whole region is $\frac{1-s}{2}+\frac{s}{\gamma}$. But the purchasing area for an $AL$ product in the deviation case is a subset of it. Thus, the deviation firm's demand is a proportion of the equilibrium demand for an $AH$ firm:

$$\frac{\frac{s}{2}+\frac{s^2}{4\gamma}}{\frac{1-s}{2}+\frac{s}{\gamma}}Q_H = \frac{\gamma s + s^2/2}{\gamma(1-s)+2s}Q_H \ .$$

Therefore, an $AL$ firm has no incentive to deviate if

$$\frac{\gamma s + \frac{s^2}{2}}{\gamma(1-s)+2s}Q_H \leq Q_L \ . \tag{5}$$

Combining (4) and (5), we can see that the proposed equilibrium can be sustained if and only if

$$\frac{\gamma s + \frac{s^2}{2}}{\gamma(1-s)+2s}Q_H \leq Q_L \leq Q_H \ ,$$

which is equal to (1) by using (2) and (3). ■

Result (i) of Proposition 1 is easy to understand. If there were such an equilibrium, categories $A$ and $B$ would identify both product types and all firms listed there would be high-quality, while category $AB$ would only list low-quality firms and would reveal no information about product type. Therefore, no consumers would ever want to search in category $AB$, and thus the firms in that category could profitably deviate.

The interesting feature of the quality revealing equilibrium in Proposition 1(ii) is that although the categories provide no explicit information about quality, in equilibrium consumers are able to perfectly infer quality from firms' category choices: the firms in category $A$ or $B$ supply low-quality products while those in category $AB$ supply high-quality products. In particular, the apparently uninformative category $AB$ now endogenously conveys quality information, and the partially informative categories $A$ and $B$ are now fully informative. However, since category $AB$ is not informative about product type, those consumers who are sensitive to product quality have to "pay" for getting a high-quality product, either by not buying their preferred product type (the region of "search $AB$") or by engaging in costly search for the right type (the regions of "actively search $AB$").

This type of equilibrium, however, only exists when condition (1) holds. When $\gamma = 1$, the region between the two curves in Figure 3 below describes the set of $(s, \alpha)$

which satisfy (1).[11] Intuitively, for a given $s$, the fraction of high-quality firms $\alpha$ cannot be too high or too low. If $\alpha$ is too high, then the market for high-quality products would be too crowded and each firm only gets a small demand. Then each high-quality firm of product $i \in \{A, B\}$ would want to switch to category $i$ where there are relatively few low-quality firms and competition each firm has a higher market share. By contrast, if $\alpha$ is too low, then the market for low-quality products would be too crowded such that a low-quality would want to list in category $AB$ and compete with high-quality firms (it will have some demand because those consumers who do not value quality highly will buy from it).

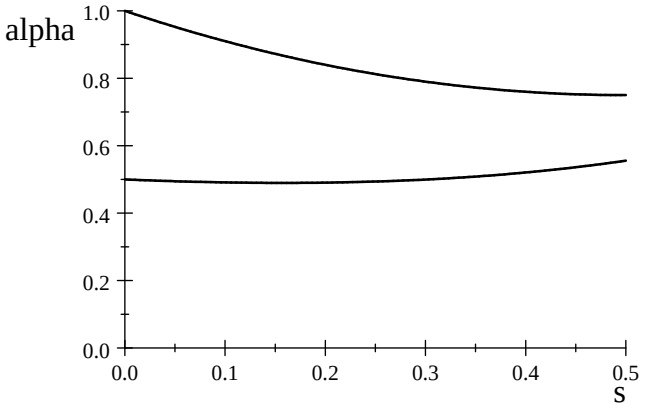


Figure 3: Condition for horizontal categorization to reveal quality information

## 3.2 Horizontal categories reveal product type information only

Under horizontal categorization, there is always an equilibrium in which horizontal categories only reveal product type information.

**Proposition 2** *(Product-type revealing equilibrium) If* $C = \{A, B, AB\}$, *there is an equilibrium in which all A firms list in category A and all B firms list in category B, independent of quality, and consumers search either in category A or B and follow the search strategy described in Figure 4 below.*

[11] When $\gamma = 1$, condition (1) simplifies to $\frac{(2+s)(s^2+1-s)}{s^3-s^2-s+4} \leq \alpha \leq 1 - s + s^2$.

**Proof.** Since consumers do not search in empty categories (Assumption 1), firms have no incentive to deviate and list in category $AB$.[12] Given firms' listing strategies, consumers with $x < \frac{1}{2}$ search category $A$ while consumers with $x \geq \frac{1}{2}$ search category $B$. In each category, a consumer searches until she finds a high-quality product if and only if $q > \frac{s}{\alpha}$. To see that, consider, for instance, category $A$. If a consumer accepts the first sampled product, her expected surplus is $v - \gamma x + \alpha q$. (Recall that the first search is costless.) If she searches until she finds a high-quality product (which needs $\frac{1}{\alpha}$ searches on average), her expected surplus is $v - \gamma x + q - (\frac{1}{\alpha} - 1)s$. The latter is greater if and only if $q > \frac{s}{\alpha}$. This optimal search strategy is illustrated in Figure 4 below. ■

For consumers this equilibrium is better than the completely uninformative equilibrium which we will discuss below since they can at least get their preferred product type without search. However, to get a high-quality product they, on average, have to search.

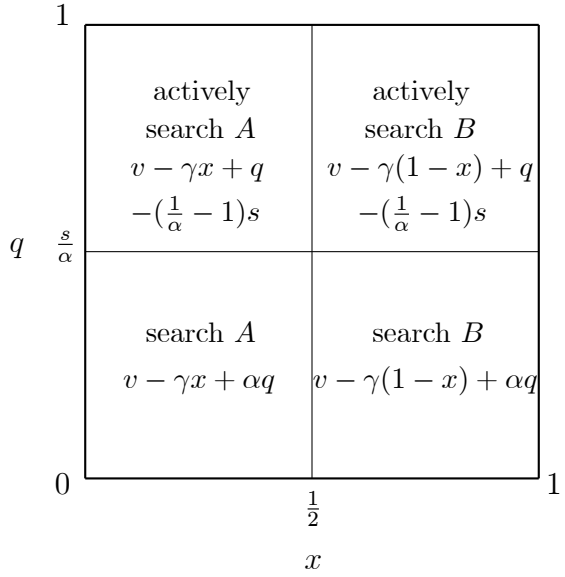


Figure 4: Pattern of demand when horizontal categories reveal horizontal information.

[12] If consumers cannot observe the deviation (e.g., category headings do not indicate the number of firms in that category), it is natural to assume that consumers will not search an empty category. If consumers can observe a deviation, the presumption that listing under an empty category leads to zero profit can be justified if consumers have the (out of equilibrium) belief that a firm which lists in category $AB$ is low quality. Given that belief, it is a dominant strategy for consumers never to search in that category.

## 3.3 Horizontal categories reveal no information

Under horizontal categorization , there is also an uninformative equilibrium where categories do not reveal any information at all. This equilibrium is equivalent to the case where there is no categorization at all.

**Proposition 3** ***(Pooling equilibrium)*** *If $C = \{A, B, AB\}$, there is always an equilibrium in which all firms list in category $AB$, and consumers search only in category $AB$ and follow the search strategy specified in Figure 5 below.*

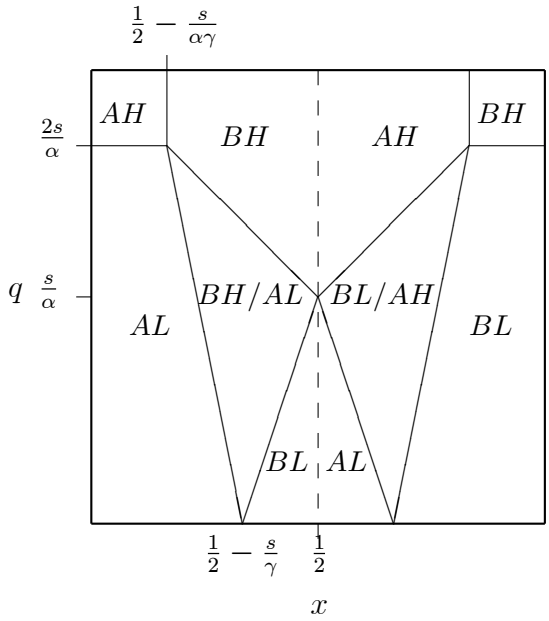


Figure 5: Pattern of demand when categorization reveals no (horizontal or vertical) information.

**Proof.** Firms have no incentive to deviate again because consumers do not search empty categories. The characterization of consumer search behavior in this case is more involved than in previous cases. Consider a consumer at $x < \frac{1}{2}$. (The case for $x > \frac{1}{2}$ is symmetric.) She values and ranks the four possible products as follows:

$$\begin{array}{l} BL \prec AL \preceq BH \prec AH \\ \Leftrightarrow v - \gamma(1-x) < v - \gamma x \leq v + q - \gamma(1-x) < v + q - \gamma x \end{array} \quad \text{if } q \geq \gamma(1-2x)$$

.

$$\begin{array}{l} BL \prec BH \prec AL \prec AH \\ \Leftrightarrow v - \gamma(1-x) < v + q - \gamma(1-x) < v - \gamma x < v + q - \gamma x \end{array} \quad \text{if } q < \gamma(1-2x)$$

In particular, if this consumer has a relatively high valuation for quality, she prefers $BH$ to $AL$ though the former is not her ideal product type. By contrast, if she has a relatively low valuation for quality, she prefers $AL$ to $BH$.

Suppose $q \geq \gamma(1-2x)$. If the consumer buys the first product she samples, her expected surplus is $v - \frac{\gamma}{2} + \alpha q$. If she only buys products no worse than $AL$, she needs to search $\frac{2}{1+\alpha}$ times on average and so her expected surplus is

$$\frac{1-\alpha}{1+\alpha}(v-\gamma x) + \frac{2\alpha}{1+\alpha}\left(v+q-\frac{\gamma}{2}\right) - \left(\frac{2}{1+\alpha}-1\right)s \ .$$

If she only buys high-quality products (i.e., product $BH$ or $AH$), she needs to search $\frac{1}{\alpha}$ times and so her expected surplus is

$$v+q-\frac{\gamma}{2} - \left(\frac{1}{\alpha}-1\right)s \ .$$

Finally, if she only buys the ideal product $AH$, she needs to search $\frac{2}{\alpha}$ times and her expected surplus will be

$$v+q-\gamma x - \left(\frac{2}{\alpha}-1\right)s \ .$$

Comparing these four options reveals the optimal search strategy when $q \geq \gamma(1-2x)$. The case of $q < \gamma(1-2x)$ can be dealt with similarly. The optimal consumer search behavior is described in Figure 5 below. There, for example, "$AH$" indicates that consumers on that region stop searching only if they find a product no worse than $AH$, and "$BH/AL$" indicates that the threshold product for consumers on that region is the worse one between $BH$ and $AL$ (depending on $q \geq \gamma(1-2x)$ or not) . ■

## 3.4 Horizontal categories and consumer welfare

We now turn to the welfare impacts of horizontal categorization on consumers. It is clear that all consumers who care about product type and/or product quality strictly prefer the quality revealing equilibrium and the product-type revealing equilibrium to the uninformative pooling equilibrium. However, between the first two, different consumers may have different assessment. With the help of Figures 2 and 4 we can compare each type of consumer's surplus under the two equilibria. For example, consumers who have

relatively low valuations for quality but care sufficiently about product type (i.e., those located on the southeast and southwest corners), prefer the product-type revealing equilibrium. In both equilibria, they get the right product type but in the product-type revealing equilibrium they also get high quality with probability $\alpha$. Consumers who have high valuations for quality and also sufficiently care about product type (i.e., those located on the northeast and northwest corners), prefer the quality revealing equilibrium if $s$ (the search cost needed to find the right product type in the quality revealing equilibrium) is less than $(\frac{1}{\alpha}-1)s$ (the search cost needed to find a high-quality product in the product-type revealing equilibrium), i.e., if the fraction of high-quality firms $\alpha < \frac{1}{2}$.

The following result compares total consumer surplus under the two equilibria.

**Proposition 4** *The quality revealing equilibrium gives rise to higher total consumer surplus than the product-type revealing equilibrium if and only if*

$$\frac{2}{3\gamma}s^2 - \left(\frac{1}{2}+\frac{1}{\gamma}\right)s + 1 + \left(\frac{s}{2\alpha}-1\right)\left(\frac{1}{\alpha}-1\right) < 0 \ . \tag{6}$$

**Proof.** Using Figure 2, one can derive that total consumer surplus in the quality revealing equilibrium is

$$v + \frac{1}{2} - \frac{\gamma}{4} - s + \left(\frac{1}{2}+\frac{1}{\gamma}\right)s^2 - \frac{2}{3\gamma}s^3 \ .$$

Using Figure 4, one can derive that total consumer surplus in the product-type revealing equilibrium is

$$v + \frac{1}{2} - \frac{\gamma}{4} - \left(\frac{1}{\alpha}-1\right)\left(s - \frac{s^2}{2\alpha}\right) \ .$$

One can check that the former is larger if (6) holds. ■

When $\gamma = 1$, the region between the two dashed curves in Figure 5 below describes the set of $(s, \alpha)$ which satisfy condition (6). The two solid curves replicate those in Figure 3 (so the quality revealing equilibrium exists only when $(s, \alpha)$ is between these two curves). Therefore, only in the region in the middle does the quality revealing equilibrium exist and generate higher consumer surplus. Beyond this region, either the quality revealing equilibrium does not exist or it is dominated by the product-type revealing equilibrium in terms of consumer welfare. As we will see in section 5, the result will be very different if we allow for free entry.

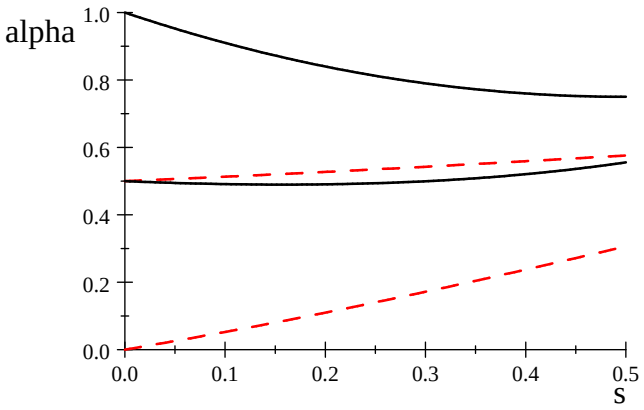


Figure 5: Horizontal categorization and consumer welfare

# 4 Vertical Categorization

Now we consider vertical categories. Examples for such categories include the five-star rating system for hotels, rating of airlines etc. Moreover, many online information intermediaries rate sellers according to customers' quality reviews. In the following, we discuss two cases in turn, depending on whether only vertical categories exist or both horizontal and vertical categories exist.

Consider first the case in which there are only vertical categories: $C = \{H, L, HL\}$. As before, there is always a trivial equilibrium in which all firms list in the same category, say $HL$, and therefore categorization provides no information. This equilibrium can again be sustained by the assumption that consumers do not search empty categories. The interesting question, however, is whether there is a separating equilibrium such that high-quality firms list in category $H$ and low-quality firms list in category $L$. When quality categories are verifiable, such a separating equilibrium trivially exists because each firm **must** list itself according to its actual quality (Since consumers do not search empty categories, an $L$ firm cannot gain by deviating and listing itself in $HL$). The outcome is different if vertical categories are not verifiable as the following proposition shows.

**Proposition 5** *Consider category structure $C = \{H, L, HL\}$. If vertical categories are not verifiable, there is no equilibrium in which high-quality firms list in category $H$ and low-quality firms list in category $L$.*

**Proof.** Suppose instead that all $H$ firms list in category $H$ and all $L$ firms list in category $L$ and category $HL$ is empty. Then, since each list contains the same proportion of $A$ and $B$ firms, every consumer gets higher utility by searching in category $H$ and therefore $L$ firms have no customers and make zero profit. Suppose an $L$ firm of type $i$ deviates and lists in category $H$. Then consumers who have relatively low valuations for quality and prefer product type $i$ will buy it if it is encountered first. Thus this $L$ firm will increase its profit by deviating. ■

Thus in our model, a category structure with unverifiable vertical categories cannot fully disclose vertical information, but a category structure with only horizontal categories (even if they are unverifiable) can lead to an equilibrium in which vertical information is fully disclosed.

Now let us consider a more "complete" category structure $C = \{AH, AL, BH, BL\}$. If both horizontal and vertical categories are verifiable, trivially there again exists an equilibrium where each type of firms lists in the right category and both product-type and quality information are revealed. But if only horizontal categories but not vertical categories are verifiable, then for a similar reason as above, there is no equilibrium in which quality information is revealed.

**Proposition 6** *Consider category structure $C = \{AH, AL, BH, BL\}$. If vertical categories are not not verifiable quality information cannot be revealed in equilibrium.*

If neither horizontal nor vertical categories is verifiable, the following type of equilibrium can be sustained under certain conditions: all $AL$ firms list in category $AL$, all $BL$ firms list in category $BL$, all high-quality firms (independent of their product type) list in category $AH$, and category $BH$ remains empty. Consumers who do not care about quality too much will search in either $AL$ or $BL$ to find the right product type. Consumers who sufficiently care about quality will search in $AH$ even though they may end up buying the wrong product type. No firms want to deviate and list

in empty category $BH$ because consumers do not search empty categories. In fact, this equilibrium is effectively the same as the quality-revealing equilibrium when the category structure is $C = \{A, B, AB\}$.

# 5 Free Entry and Endogenous Product Quality

Thus far we have assumed that the distribution of quality is exogenously given. Extending our model to consider free entry of different types of firms can allow us to investigate the effect of categorization and the different type of equilibria that we discussed in the previous sections on the percentage of high quality firms in the industry. We thus consider a model in which firms can enter an industry but there are entry costs. Suppose the entry cost for a high-quality firm is $F_H$ and the entry cost of a low-quality firm is $F_L$; $F_L < F_H$. We focus on the horizontal category structure $C = \{A, B, AB\}$ since considering (unverifiable) vertical categories cannot lead to more informative new equilibria. We assume that firms enter the industry as long as their profits cover their entry costs. Since the firms' profits depend on the categorization equilibrium there is an interdependence between the category structure and the type of equilibrium in the market and the percentage of firms of each type. Our main result is presented in the following proposition. Its proof and the properties of the resultant market structure are derived with the aid of three lemmas that are presented after the proposition.

**Proposition 7** *In a free-entry market with a sufficiently small search cost $s$, both the quality revealing equilibrium and the product-type revealing equilibrium exist, and the quality revealing equilibrium induces a higher fraction of high-quality firms and leads to greater consumer surplus.*

In order to prove this proposition we first investigate the conditions under which the quality revealing equilibrium in Proposition 1 exists in a free-entry setting. It turns out that when search costs are sufficiently small this equilibrium always exists in a free-entry environment.

Let $n$ be the total measure of firms in the free-entry equilibrium, and $\alpha$ be the fraction of high-quality firms as before.

**Lemma 1** *In a free-entry market, if the condition*

$$\frac{s(2+s/\gamma)}{2(1-s+2s/\gamma)} \leq \frac{F_L}{F_H} \tag{7}$$

*holds, there exists a quality revealing equilibrium where the fraction of high-quality firms is*

$$\alpha = \left(1 + \frac{F_H}{F_L}\frac{s-s^2/\gamma}{1-s+s^2/\gamma}\right)^{-1} . \tag{8}$$

*In particular this equilibrium always exists for sufficiently small search costs.*

**Proof.** If a quality revealing equilibrium exists, from (2) and (3) we know that the profit of a high-quality firm and the profit of a low-quality firm (without considering the entry cost) are respectively

$$\pi_H(n,\alpha) = \left(1-s+\frac{s^2}{\gamma}\right)\frac{m}{n\alpha} \ ; \ \pi_L(n,\alpha) = \left(s-\frac{s^2}{\gamma}\right)\frac{m}{n(1-\alpha)} \ .$$

Then the free-entry conditions are

$$\left(1-s+\frac{s^2}{\gamma}\right)\frac{m}{n\alpha} = F_H \ ; \ \left(s-\frac{s^2}{\gamma}\right)\frac{m}{n(1-\alpha)} = F_L \ .$$

They determine $n$ and $\alpha$. In particular, one can solve

$$\alpha = \frac{1}{1+\frac{F_H}{F_L}\frac{s-s^2/\gamma}{1-s+s^2/\gamma}} \Leftrightarrow \frac{\alpha}{1-\alpha} = \frac{F_L}{F_H}\frac{1-s+s^2/\gamma}{s-s^2/\gamma} \ .$$

Recall that the condition for the quality revealing equilibrium is (1):

$$\frac{2+s/\gamma}{2(1-s/\gamma)}\frac{1-s+s^2/\gamma}{1-s+2s/\gamma} \leq \frac{\alpha}{1-\alpha} \ \leq \frac{1-s+s^2/\gamma}{s-s^2/\gamma} \ .$$

The second half of this condition holds given $F_L < F_H$. One can check that the first half of the condition also holds if and only if (7) is satisfied. ■

Therefore, at least for small search friction, allowing for free-entry of quality actually increases the likelihood that a quality revealing equilibrium exists. To illustrate condition (7), let us consider the example with $\gamma = 1$ (and so $s < \frac{1}{2}$ from the assumption of $s < \min\{\frac{1}{2}, \frac{\gamma}{2}\}$). The left-hand side of (7) increases from 0 to $\frac{5}{12}$, and so the quality revealing equilibrium exists for any search cost $s < \frac{1}{2}$ if $\frac{F_L}{F_H} \geq \frac{5}{12}$.

We then turn to the product-type revealing equilibrium.

**Lemma 2** *In a free-entry market, if* $s < \frac{F_L}{F_H}$*, there exists a product-type revealing equilibrium where the fraction of high-quality firms is*

$$\alpha = \left(1 + \frac{1}{s} - \frac{F_H}{F_L}\right)^{-1} \in (s, 1) \ . \tag{9}$$

**Proof.** If the product-type revealing equilibrium exists, a high-quality firm's profit is

$$\pi_H(n, \alpha) = (1 - \min\{1, \frac{s}{\alpha}\})\frac{m}{n\alpha} + \min\{1, \frac{s}{\alpha}\}\frac{m}{n} \ .$$

For those consumers with $q > \frac{s}{\alpha}$, a high-quality firm is competing only with other high-quality firms. But for those with $q < \frac{s}{\alpha}$, it is competing with all firms. (Note that we need to take into account the possibility that $\frac{s}{\alpha} > 1$.) For a low-quality firm, only those consumers with $q < \frac{s}{\alpha}$ may patronize it and it is competing with all other firms. Hence, a low-quality firm's profit is

$$\pi_L(n, \alpha) = \min\{1, \frac{s}{\alpha}\}\frac{m}{n} \ .$$

The free-entry conditions are then:

$$(1 - \min\{1, \frac{s}{\alpha}\})\frac{m}{n\alpha} + \min\{1, \frac{s}{\alpha}\}\frac{m}{n} \leq F_H \ ; \ \min\{1, \frac{s}{\alpha}\}\frac{m}{n} \leq F_L \ .$$

(We allow weak inequalities because corner solutions may exist in this case.) Then one can show that the equilibrium described in the lemma exist when $s < \frac{F_L}{F_H}$.[13] ■

The above two lemmas indicate that both the quality revealing equilibrium and the product-type revealing equilibrium exist if both $s < \frac{F_L}{F_H}$ and (7) are satisfied. One can check that they are equivalent to the condition

$$\frac{F_H}{F_L} < \min\left\{\frac{1}{s}, \frac{2(1 - s + 2s/\gamma)}{s(2 + s/\gamma)}\right\} \ . \tag{10}$$

We next compare in the following Lemma the fraction of high-quality firms and consumer welfare between these two equilibria:

[13] There are also two product-type revealing equilibria with corner solutions: (i) There always exists a free-entry equilibrium with $\alpha = 0$ (i.e., only low-quality firms enter the market) in which each firm earns $\frac{m}{n} = F_L$. (ii) When $s < \frac{F_L}{F_H}$, there exists a free-entry equilibrium with $\alpha = 1$ (i.e., only high-quality firms enter the market) in which each firm earns $\frac{m}{n} = F_H$.

**Lemma 3** *(i) If the condition*

$$\frac{F_H}{F_L} < \frac{1 - s + s^2/\gamma}{s} \tag{11}$$

*holds, both equilibria exist and the quality-revealing equilibrium induces a higher proportion of high-quality firms than the product-type revealing equilibrium.*
*(ii) If the conditions (10) and*

$$\frac{2}{3\gamma}s^2 - \left(\frac{1}{2} + \frac{1}{\gamma}\right)s + 1 + \frac{s}{2}\left(1 - \frac{1}{s} - \frac{F_H}{F_L}\right)\left(\frac{1}{s} - \frac{F_H}{F_L}\right) < 0 \tag{12}$$

*hold, both equilibria exist and the quality-revealing equilibrium gives rise to higher consumer surplus than the product-type revealing equilibrium.*

**Proof.** (i) It is ready to derive (11) by comparing (8) and (9). One can also check that under the assumption of $s < \min\{\frac{1}{2}, \frac{\gamma}{2}\}$, (11) implies (10) and so both equilibria exist.

(ii) From the analysis in section 3.4, we can see that consumer welfare in the quality revealing equilibrium does not depend on $\alpha$. Therefore, the condition for the quality revealing equilibrium to generate higher consumer welfare is the same as before:

$$\frac{2}{3\gamma}s^2 - \left(\frac{1}{2} + \frac{1}{\gamma}\right)s + 1 + \left(\frac{s}{2\alpha} - 1\right)\left(\frac{1}{\alpha} - 1\right) < 0 \ ,$$

except that $\alpha$ is now given in (9). Substituting (9) into this inequality yields (12). ■

To prove Proposition 7 note that when the search cost $s$ is close to zero, both conditions (11) and (12) are satisfied. Therefore, at least when the search friction is small, consumers prefer the quality revealing equilibrium.

# 6 Discussion and Concluding Comments

We have considered a very specific setup of search with categories. Clearly there are different aspects of search markets with categories that are important and deserve a more careful analysis. In our concluding section we discuss some of these issues and their potential effect on market analysis.

*Multiple listings.* In our basic setup each firm chooses one category. When the model is interpreted in terms of advertising or positioning by firms, it is natural to assume that a firm can list under one category only. But when categorization is implemented by an intermediary such as a search engine, it may be necessary to extend the model to allow for the possibility that firms may list under multiple categories. One possibility is that firms choose a subset of the provided categories in which to list where the cost of listing is determined by specific market arrangements. Formally, our model can handle such situations by modifying the firms' strategy choice from a single category to a subset of categories. Another possibility is that multiple listings are automatically implemented by the search engine, so that when a firm chooses to list in a narrow category, it is automatically also listed in a more general category. For example, if a firm lists under category $A$ its also automatically appears in category $AB$. We provide a brief analysis of the latter case in the following paragraph in order to demonstrate the possible effects of multiple listing.

Consider the horizontal category structure $C = \{A, B, AB\}$ and suppose that if a type-$i$ firm chooses to list in category $i \in \{A, B\}$, it will automatically appear also in the more general category $AB$. Consider a possible product-type revealing equilibrium first. Suppose all $A$ firms choose to list in category $A$ and all $B$ firms choose to list in category $B$. Then all firms will also appear in category $AB$. Given that consumers will only search in either category $A$ or category $B$, no firms want to list in category $AB$ only. Therefore, a similar product-type revealing equilibrium always exists even if we allow multiple listings.[14]

Now consider a possible quality revealing equilibrium. Suppose $AL$ type firms choose to list in category $A$ and $BL$ firms choose to list in category $B$, and all high-quality firms choose to list in category $AB$. Then the automatic multi-listing implies that all firms will actually appear in category $AB$. Compared to the case with single listing, quality information is not totally revealed and the expected quality of category $AB$ becomes lower. But this cannot be sustained as an equilibrium because a high-quality firm can always do better by listing in category $i$. In fact, given the automatic enrollment into

[14]It is also easy to see that it is still an equilibrium that all firms list in category $AB$ given that consumers do not search empty categories.

category $AB$, listing in category $A$ or $B$ weakly dominates listing in category $AB$. This result implies that whenever intermediaries wish to design the rules of category affiliation they need to take into account the fact that multi-listing may destroy the possibility of using categories to signal the firms' quality.

*Endogenous consumer participation.* Our analysis has assumed full-market coverage, i.e., all consumers buy the product. But search with categories may have interesting implications regarding the number of consumers participating in the market. When there is no categorization (or if the uninformative pooling equilibrium prevails), some consumers may opt out of the market because they anticipate an inefficient search process. For example, assume that most of the firms are type $A$ and there are very few type $B$ firms and consider a consumer with a very strong preference for type $B$ product. Searching for type $B$ may be very costly and therefore the consumer is better off not entering the market. Clearly horizontal categorization may solve the problem as it makes it easier for the consumer to find the product that he likes and therefore it may induce this consumer to participate in the market.

*Platform design.* Generally the category structure is chosen by the information platform. For example, Yelp.com can choose how many categories of restaurants to have. So in addition to the fee structure that is often discussed in the literature, how to design the category structure is an important decision for the platform. It will affect both consumers' willingness to use the information service and firms' listing strategies and their willingness to list in the platform.

*Prominence and Categorization.* The standard search setup assumes that all the objects (the firms in our case) are randomly sampled, each with the same probability. The search and prominence literature assumes that objects may be sampled with different probabilities, such that a more prominent object is sampled with a higher probability. The objects' prominence can be either exogenously given or endogenously determined by the firms' activities. An interesting extension would be to introduce prominence into our mdoel of search with categories. Specifically, firms may have different prominence in different categories (when prominence is determined exogenously). Thus the firms' category choice may depend also on its prominence in the different categories and not just on the categories' signalling value. When prominence is endogenously determined,

say by advertising, it may be that the cost of achieving prominence is different for different categories which again may affect the firms' category choice. Such an extension is beyond the focus of this paper and may hold promise for interesting future research.

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