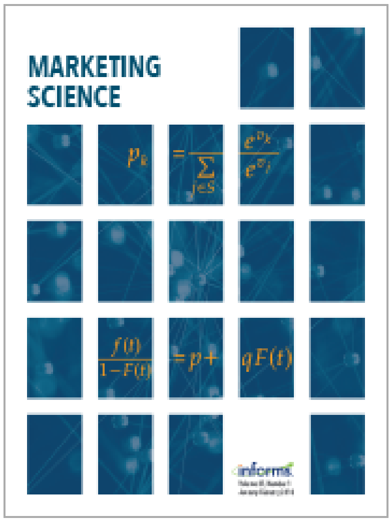

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Lowering Customer Evaluation Costs, Product Differentiation, and Price Competition

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When match uncertainty is resolved via costly evaluation, the first product sampled by a customer is more likely to make the sale. This prompts firms to lower their products' evaluation costs to attract customers to sample their products first. Such efforts by firms are called customer learning investment (CLI). When product quality is freely observable but horizontal match is not, we examine how CLI choices interact with quality and price competition in a duopoly. CLI has a *competition effect* in that a higher CLI of a firm increases its demand but decreases that of its rivals. In the market-covered duopoly, both qualities will decrease (increase) when the high-end (low-end) firm invests more in customer learning, and remain unchanged when they invest equally, relative to when neither firm invests. We further show that the firm with a higher relative production efficiency invests more in customer learning than the competitor. In the market-not-covered duopoly, CLI by the low-end firm also creates a *market-expansion effect* by inducing some additional low-end customers to sample and purchase its product. This may induce it to invest more than the high-end firm, even when the latter has a higher relative production efficiency.

Keywords: customer learning; evaluation; product quality; search; vertical differentiation
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1. Introduction

In markets such as apparel, appliances, consumer electronics, cars, software, and industrial goods, customers often spend considerable time and effort to ascertain whether and how a product meets their idiosyncratic needs (Shread 2012).[1] Because customers recognizing a good match with a product have reduced incentive to continue to evaluate other products, each firm attempts to lower the evaluation costs of its product, hoping to woo prospective buyers to evaluate its product first. Examples abound. Some retailers run free shuttle services through major residential locations. Software vendors develop demo versions and easy to follow user manuals. Producers of enterprise software and other industrial goods maintain sales teams to showcase their products and to address questions from interested buyers.

More important, firms' product quality decisions and efforts to lower customers' evaluation costs seem to affect each other. The four antidepressants with superior quality, i.e., Sertraline, Paroxetine, Fluoxetine, and Citalopram, use stronger sampling intensities than the other antidepressants (Gu and Xie 2013). In apparel retailing, Saks Fifth Avenue offers higher quality products and sales support than Macy's, which in turn offers better products and services than Walmart. At Apple's experience centers and stores, well trained staff introduce various product features to prospective buyers and help with their technical issues (*Wall Street Journal* 2011). As Samsung improved its product quality in recent years, it also opened its own mini stores in more than 1,400 Best Buy stores (*Wall Street Journal* 2013). Although we lack direct evidence that firms' product quality decisions depend on their effort to lower customers' evaluation costs, Apple's story indicates that such a linkage is plausible. A widely held belief is that it is Apple's superior products that draw traffic into its physical stores. Its phenomenal investment in physical stores and associated staff training leads us to expect that it will continue to develop high quality products because if its product quality deteriorates and fewer people visit its stores, the investment would be wasted.

In a duopoly, we investigate the firms' effort to ease customer evaluation of product match, hereafter called CLI, and how it interacts with their quality choices and pricing. We address several questions. First, how do the firms' CLIs affect their pricing? Second, how do product qualities change relative to when neither firm invests in customer learning, and

[1] Another example is certain financial products. For example, brokers that sell complex financial securities prepare reports and host seminars to help potential buyers determine whether the securities suit their needs (Madan and Soubra 1991).

how does the production technology drive their CLIs? Third, because the market may not be fully covered in relatively young industries, how does the equilibrium differ for covered and noncovered markets? How do the simultaneous and sequential choices of CLI and quality affect the market outcome differently? Last, when product development requires a fixed research and development (R&D) cost, how does CLI drive quality provision?

Our baseline model is outlined as follows. The two firms each offer a single product with a vertical and horizontal attribute. Customers have heterogeneous preference for quality. Whereas each product's quality and price are assumed to be costlessly observable, its horizontal match is idiosyncratic and can only be determined via costly evaluation.[2] For simplicity, we assume the two products' match values are identically and independently distributed across customers. Each firm can lower customers' cost of evaluating its product by making proper investments. We consider a two-stage game wherein the firms first choose and commit to quality and CLI and then compete in price. Observing the decisions of both firms and her own preference for quality, each customer determines her optimal search and purchase strategy. The firms' demand then realizes.

Our main analysis focuses on a market-covered duopoly, where total industry demand is fixed. Here we reveal the *competition effect* of CLI: The demand of the firm making a larger CLI expands, at the expense of the competitor. Consequently, the price of the firm with a larger CLI increases whereas the other's decreases relative to when neither firm invests in customer learning. Symmetric investments do not affect the firms' demand and prices.

For fixed product qualities, we show that the firm with a production efficiency advantage makes a larger CLI because it enjoys a higher marginal return from CLI. If the products' unit cost difference is below their utility difference for the average customer, the high-end firm has a higher relative production efficiency and invests more in customer learning. The low-end firm invests more otherwise.

When the firms endogenize both product quality and CLI, we obtain two results. First, if the high-end (low-end) firm makes a greater CLI both product qualities will decrease (increase) relative to when neither firm invests. The reason is that the firms' relative CLIs affect their demand elasticities of *quality*. The demand elasticity of quality of the high-end firm is negative and that of the low-end firm is positive.[3] A greater CLI by the high-end firm increases its own demand elasticity and decreases the other's, prompting both firms to lower their qualities. The case wherein the low-end firm makes a greater CLI is analogous.

Second, the high-end firm invests more in customer learning if each firm's quality is below a respective threshold, and the low-end firm invests more otherwise. As in the case of fixed qualities, here the firms' (endogenous) relative production efficiencies drive their relative CLIs. The greater the ratio between the firms' unit cost difference and quality difference, the higher the low-end firm's relative production efficiency (and the lower the high-end firm's), as we assume unit production cost is a convex function of quality. When both qualities are low (high), the high-end (low-end) firm has a higher relative production efficiency and makes a larger CLI.

The main analysis is extended in a few directions. First, we examine the market-not-covered duopoly, where the firms choose CLIs first, select product quality next, and set prices last. When the market is not covered, CLI by the low-end firm introduces a *market-expansion effect* (beside the competition effect): Some of the low-end customers would not participate in the absence of CLI, but will now sample (and purchase in case of a good match) the low-end product. This leads to some new results. When their CLIs are sufficiently close to each other, both firms' prices increase relative to when neither firm invests in customer learning. Which firm makes a larger CLI depends not only on its relative production efficiency but also on the cost of the CLI. In particular, when unit production cost remains constant over quality (so that the high-end firm has a production efficiency advantage), the low-end firm invests more if the cost of the CLI is sufficiently low, and the high-end firm invests more otherwise. Second, we analyze the three-stage CLI-quality-price game in a market-covered duopoly. When unit production cost remains constant over quality, the high-end firm's CLI (weakly) dominates that of the low-end firm, consistent with our baseline model. This contrasts with the market-not-covered case and highlights the role of the market-expansion effect of CLI. Third, we study the effect of CLI on R&D competition. Whereas the low-end quality remains intact (at the lowest permissible quality), CLI lowers the high-end quality relative to when neither firm invests.

The current paper is related to the literature on consumer search. Whereas the early literature on

[2] Some quality-type attributes such as the material of a sweater (cashmere, regular wool or polyester), ease of use of software, resolution of digital camera, speed and memory size of digital devices, and safety and fuel efficiency of cars seem easy enough to communicate by the firms themselves or authoritative third parties.

[3] In the stage-one game, the demand of the high-end firm increases as its quality decreases, and that of the low-end firm increases as its quality increases. Later we say that a firm's demand elasticity of quality increases if its absolute value increases.

search largely focuses on price search in markets of homogeneous goods, several models examine markets with exogenous product differentiation (Wolinsky 1986, Bakos 1997, Lal and Sarvary 1999, Anderson and Renault 1999). More recently, researchers have begun to examine the role of search in product design. In the horizontal duopoly of Kuksov (2004), consumers costlessly observe the product attributes but incur a search cost to discover price, and the firms are uncertain about consumers' valuation. He finds that lower search costs may lead to greater product differentiation and hence higher prices. Bar-Isaac et al. (2011) show that lower search costs induce firms to choose extremal (most broad or most niche) product designs. Mehta et al. (2003) and Liu and Dukes (2013) develop search theoretic models of consideration set formation. Bergen et al. (1996), Cachon et al. (2008), Kuksov and Villas-Boas (2010), and Villas-Boas (2009) focus on the role of search or evaluation cost in multiproduct firms' variety choices. Unlike our current paper, however, none of these papers examines the impacts of search on firms' product quality choices.

Our model also relates to those papers on vertical differentiation and product line design. Mussa and Rosen (1978) and Moorthy (1984) provide early monopoly models of vertical product line design, focusing on how to mitigate cannibalization within the line. Desai et al. (2001) examine the trade-offs of component commonality in product line design. In a duopoly, Shaked and Sutton (1982), Moorthy (1988), and Lehmann-Grube (1997) show that the firms choose differentiated qualities to relax price rivalry under various cost structures.[4] In an oligopoly, Jing (2006) examines how the firms' relative cost efficiencies may drive their profitability. Desai (2001), Jing and Zhang (2011), and Villas-Boas and Schmidt-Mohr (1999) present competitive models of product line design and pricing. In these models, consumers have perfect information about the characteristics and prices of the products offered. In our model, quality and price are freely observable, but horizontal match is not. We analyze how firms' efforts to lower customers' costs of evaluating match interact with their quality and pricing decisions.

The role of CLI in our model is somewhat reminiscent of informative advertising (Anderson and Renault 2009, Grossman and Shapiro 1984, Iyer et al. 2005, Meurer and Stahl 1994, Soberman 2004). In models of informative advertising, those exposed to advertisements are assumed to costlessly learn the value of advertised attributes whereas the other consumers remain uninformed (Grossman and Shapiro 1984) or resort to search (Desai et al. 2010). Similarly, information provided by the firm is also assumed to inform consumers about their product valuation (Lewis and Sappington 1994, Guo and Zhao 2009, and Gu and Xie 2013). Therefore, advertising and information provision are treated as perfect substitutes for consumer search. However, whereas advertising may fully convey relatively simple product attributes, in the market scenarios noted above firms' advertising and efforts to provide information rarely eliminate search, although they effectively lower customers' evaluation costs. Whereas Rajiv et al. (2002), Anderson and Renault (2009), and Gu and Xie (2013) examine how the sellers' exogenous quality levels affect their advertising and information provision decisions, we also show how firms' customer learning efforts may impact their endogenous quality choices. In a setting with identical products and service free riding, Desai et al. (2010) examine retail competition in service and price advertising. However, such free riding may not arise when the firms offer distinct products (as in our model).

Guo and Zhao (2009) and Liu and Xiao (2013) study firms' decisions to disclose *quality*. Guo and Zhao (2009) show that competition may lead firms to reveal less information than a monopolist, whereas Liu and Xiao (2013) focus on how quality disclosure affects channel interactions. In the monopoly model of Guo and Zhang (2012) and the duopoly model of Kuksov and Lin (2010), consumers are ex ante uncertain about their *preference for quality*. Kuksov and Lin (2010) highlights the free riding in either firm's provision of preference-revealing information. In Guo and Zhang (2012), consumers incur a deliberation cost to discover their quality preference. They show that firm profit, consumer surplus, and social welfare can all increase with consumers' deliberation cost. Our information environment contrasts with these models: Quality is common knowledge and each customer knows her quality preference. Instead, *match* is unknown and discovered via costly evaluation.

Jing (2011) examines a monopolist's optimal investment in facilitating consumer learning of product valuation and dynamic pricing of a durable good, and finds that it underinvests for low and high unit costs but may overinvest for intermediate unit costs. Gu and Liu (2013) study how a strategic retailer may benefit from manipulating consumers' search cost through shelf layout. They show that the retailer benefits more from displaying products in distant locations (i.e., increasing search cost) as the difference between their fit probabilities increases. When consumers face search costs, Iyer and Kuksov (2012) analyze retail competition to attract shoppers by investing in the shopping experience. By contrast, we

[4] Shaked and Sutton (1982) and Moorthy (1988) assume zero and convex unit variable costs, and Lehmann-Grube (1997) assume a convex fixed cost of quality.

focus on firms' incentives to lower customers' evaluation costs. Besides, product demonstrations (Heiman and Muller 1996) and return policies (Davis et al. 1995, Hess et al. 1996), as special forms of customer learning investments, both help mitigate customers' match uncertainty.

A model is developed in §2. Section 3 characterizes customers' optimal search behavior and the equilibrium in a market-covered duopoly. Section 4 explores a few extensions. Two benchmarks of the model are presented in §5. Section 6 summarizes this paper, discusses some of its limitations, and suggests avenues for future research. The appendix provides proofs of Propositions 2 through 6. The other proofs and deductions are given in the online appendix (available as supplemental material at http://dx.doi.org/10.1287/mksc.2015.0918).

2. Model

Consider a duopoly wherein each firm produces a single product. Each product has two attributes, one vertical and the other horizontal (as in Desai 2001). Let q_i ($i = 1, 2$) denote firm i's quality. The products differ in quality. Without loss of generality, let product 1 have a higher quality, i.e., $q_1 > q_2 > 0$.[5] Customers differ in their valuation of quality and each demand at most one unit of the product. Following Mussa and Rosen (1978) and Moorthy (1988), we assume that a customer of type θ derives utility θq_i from a product of quality q_i. Here θ represents the customer's constant marginal willingness to pay for quality, and is uniformly distributed over $[b, 1+b]$, where $\frac{1}{4} < b < 1$. The customer obtains an additional utility v that reflects the match between her idiosyncratic need and each product's horizontal attribute. Therefore, customer θ receives surplus $\theta q_i + v - p_i$ from buying product i at price p_i. The two products' match values are identically and independently distributed across customers. For simplicity, we assume that $v = r$ with probability λ ($r > 0$ and $0 < \lambda < 1$), and that $v = 0$ otherwise. A product is said to yield a good match when $v = r$ and a poor match when $v = 0$. We assume that r is sufficiently low relative to customers' valuation of quality, which ensures that the higher quality firm charges a higher price in equilibrium (see §§3.2 and 4.1 below). The distributions of customer type and match value are common knowledge, but each customer's type θ is known only to that customer.

We assume that each product's quality and price are costlessly observable, as in Anderson and Renault (2009), Guo and Zhang (2012), and Gu and Xie (2013). However, its match value is idiosyncratic and can only be discovered via evaluation by each customer. In several markets, prices and certain quality attributes (e.g., speed and memory of computers, resolution of digital camera, safety of cars, etc.) are well publicized by the firms themselves or authoritative third parties (such as Consumer Reports, Edmunds.com, and cNet.com). However, potential customers frequently devote time and effort to gauging how the products' horizontal features (e.g., size of clothing and shoes, interface of digital devices, exterior and interior design of cars, whether a piece of furniture suits the intended space) meet their specific needs. In addition, brands may develop certain quality reputations over time. When such mature brands release new products, they are still inspected for potential match before purchase. In the absence of firm intervention, each customer incurs cost s to evaluate either product. Throughout, we assume that $s \leq \lambda(1-\lambda)r$.

The evaluation cost includes time to visit a seller and to inspect its product. Following convention (Anderson and Renault 2006, Hauser and Wernerfelt 1990, Wolinsky 1986) we assume customers always incur the search or evaluation cost to purchase a product. This is plausible if returns are infeasible or costly. When buying a product requires visiting the seller, the customer may just evaluate its match before the transaction (e.g., as with clothes and shoes). For a technological product (e.g., digital device or software), evaluation is also the process of learning how to use it. Therefore, the customer would rather evaluate it before purchase.

The firms face the same technologies. Production has zero fixed costs. Following convention, we assume that the unit production cost, $c(q)$, is constant at any quality level and is an increasing, convex function of quality q. Each firm can also choose to lower customers' cost of evaluating its product. Specifically, by making an investment of k_i, firm i ($i = 1, 2$) lowers its product's evaluation cost to $(1-k_i)s$.[6] Firm i incurs a fixed cost $h(k_i)$ to invest k_i regardless of how many potential customers actually evaluate its product. Zettelmeyer (2000) similarly assumes that

[5] Designating one of the firms (firm 1) as the high-quality firm eases exposition. In the following analysis, it is understood that there is an otherwise identical subgame perfect equilibrium wherein firm 2 offers the higher quality.

[6] Alternatively, we may also model the impact of CLI k_i as lowering product i's evaluation cost by an absolute amount (rather than by a percentage). This alternative assumption does not significantly alter the analysis and results. To see this, when k_i lowers product i's evaluation cost to $s - k_i$, its reservation price (see §3.1 for construction) R_i satisfies $R_i = -(s-k_i) + \lambda(\theta q_i - p_i + r) + (1-\lambda)R_i$, or equivalently, $R_i = \theta q_i - p_i + r - (s-k_i)/\lambda$. We can easily verify that the firms' demand functions (in Equations (8) and (9)) and the price equilibrium (in Equations (10) and (11)) continue to hold after setting $s = 1$. Proposition 1 thus remains intact. We can further verify that the firms' stage-1 profit functions (given by Equations (12) and (13)) and Proposition 2 hold after setting $s = 1$. Propositions 3 and 4 also remain intact. The equilibrium k_1^* and k_2^* in Equations (16) and (17) and Proposition 5 continue to hold after setting $s = 1$.

the firm incurs a fixed cost to set consumers' search cost of its product. We assume that $h' > 0$ and $h'' > 0$ for $0 \le k_i < 1$ and that $\lim_{k_i \to 1-} h'(k_i) = \infty$, so that it is infeasible to entirely eliminate a product's evaluation cost. Such fixed investment may include developing a demonstration version of the software, devising user-friendly manuals, maintaining a sales team to assist evaluation, and building experience centers. All else equal, a customer will first sample the product that is easier to evaluate, and may stop her search and purchase after realizing a good match. Therefore, beside quality and price, ease of evaluation is another key dimension for potential differentiation, especially for products with match uncertainty. We shall focus on the strategic impacts of CLI and its interplay with the firms' quality and price decisions.

Both firms and customers are risk neutral and maximize their own expected payoffs. Competition unfolds in two stages. In stage one, the firms simultaneously announce and commit to product qualities q_i and CLI k_i. In stage two, observing q_1, q_2, k_1, and k_2 the firms set prices p_i simultaneously.[7] Finally, observing both firms' qualities, CLIs, and prices, each customer decides on her optimal search strategy. Following convention, we assume that search is without replacement and with free recall. Here we also assume that the firms' CLIs, just like qualities and prices, are ex ante observable to customers. Indeed, the efficacy of many firms' experience centers (e.g., those of Apple) are well known. Some retailers are known for providing better in-store services than others. Prospective buyers can readily discern the extent of evaluation assistance through a seller's website, a telephone call, or word of mouth.

3. The Market-Covered Duopoly

Our main analysis focuses on the case wherein each customer purchases one of the goods. The market is covered when $bq_2 - p_2 \ge 2s$, which holds in equilibrium when b is sufficiently high (see below). The market-not-covered case is postponed to §4.

3.1. Customer Search

Each customer's optimal search strategy in our model is given by Weitzman (1979). Weitzman (1979, p. 643) addresses the following general problem (which he calls "Pandora's problem"). A risk-neutral agent faces n closed boxes. Box i ($1 \le i \le n$) contains a reward of x_i, which follows an independent distribution F_i. It costs s_i to open box i to learn its reward.[8] When search stops, the consumer collects the highest reward uncovered. In this setting, what is the optimal search and stopping rule?

In a majority of the extant search models, all boxes are identical and thus search sequence does not matter. As is already well known, search stops once the highest reward uncovered equals or exceeds a reservation price. The reservation price has the defining property that the agent is indifferent between accepting a reward equal to the reservation price and continuing to search.

Remarkably, when the boxes are different (each with its own reward distribution and search cost), Weitzman (1979) shows that the optimal search policy still takes a reservation price form. Each box i's *reservation price* R_i is uniquely defined by $R_i = -s_i + R_i \int_0^{R_i} dF_i(x_i) + \int_{R_i}^{\infty} x_i \, dF_i(x_i)$. The left-hand side (LHS) of this equation is a known reward R_i, and its right-hand side (RHS) is the expected net surplus (net of search cost) from sampling box i. That is, when presented with a known reward R_i, the agent is indifferent between accepting it and continuing to open box i.[9] Equivalently, $\int_{R_i}^{\infty} (x_i - R_i) \, dF_i(x_i) = s_i$. The optimal search sequence is in descending order of reservation prices and search ends once the highest uncovered reward equals or exceeds the reservation price of every closed box (see Weitzman 1979, pp. 646–647).

In our current model, each customer's decision problem is a special case of that in Weitzman (1979). We consider two products ($n = 2$), each with three attributes: quality, price, and match. Whereas quality and price are costlessly observable, match is unknown and costly to observe. Therefore, each product's total value remains unknown and costly to observe. The products have a common and independent binary distribution of match value but potentially different search costs $(1 - k_i)s$, which depend on the firms' investment in customer learning k_i.[10] Because our customers have heterogeneous (marginal) valuation for quality (θ), they may differ in their optimal search policies. Letting R_i denote product i's *reservation price* for customer θ, we have $R_i = -(1-k_i)s + \lambda[\theta q_i - p_i + r] + (1-\lambda)R_i$, or equivalently

$$R_i = \theta q_i - p_i + r - \frac{(1-k_i)s}{\lambda}, \tag{1}$$

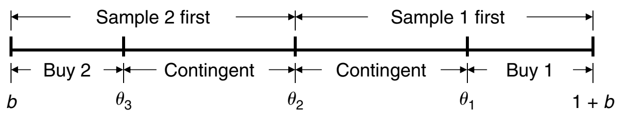
[7] In §§4.1 and 4.2, we consider a three-stage game wherein the firms choose CLI k_i first, quality q_i next, and price p_i last, in market-not-covered and market-covered duopolies, respectively.

[8] Weitzman's formulation of Pandora's problem also accommodates time-lagged learning, where the reward of box i is known after a time lag of t_i and where Pandora maximizes (expected) discounted present value. As noted by Weitzman, instantaneous learning (as we consider) is the special case $t_i = 0$.

[9] An alternative interpretation provided by Weitzman (1979, p. 646) is the following: Suppose, hypothetically, there are an infinite number of only type-i boxes. Then R_i represents the expected surplus (net of search cost) of following the optimal search strategy.

[10] Each product i's total value for customer θ thus also follows a binary distribution: It equals $\theta q_i - p_i + r$ with probability λ and equals $\theta q_i - p_i$ with probability $1 - \lambda$. Weitzman (1979, p. 648) provides a similar example with a binary value distribution.

Figure 1 Segmentation in the Market-Covered Duopoly



which increases with firm i's CLI, k_i.[11] Letting $a_i \equiv r - (1-k_i)s/\lambda$ (which may be viewed as the reservation price associated with product i's horizontal attribute alone), we have

$$R_i = \theta q_i - p_i + a_i. \tag{2}$$

Next, we characterize each customer's optimal search and stopping rule. Let

$$\theta_1 \equiv \frac{p_1 - p_2 + a_2}{q_1 - q_2}, \tag{3}$$

and

$$\theta_3 \equiv \frac{p_1 - p_2 - a_1}{q_1 - q_2}. \tag{4}$$

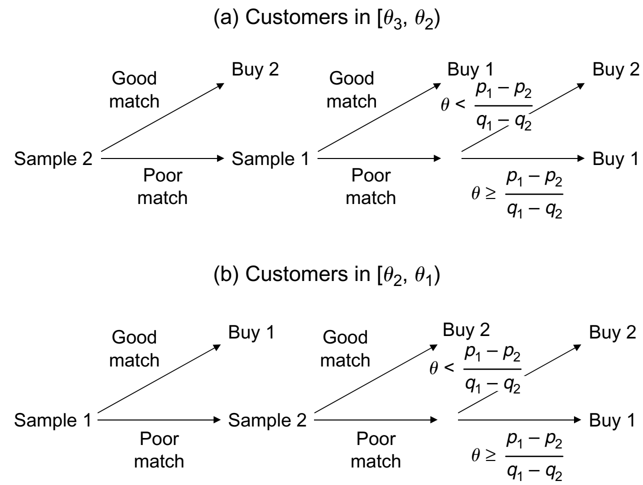
By Weitzman (1979), a customer θ will first sample product 1 if its reservation price is greater than that of product 2, i.e., $\theta q_1 - p_1 + a_1 \geq \theta q_2 - p_2 + a_2$ or

$$\theta \geq \theta_2 \equiv \frac{p_1 - p_2 - (a_1 - a_2)}{q_1 - q_2}. \tag{5}$$

Otherwise, she will first sample product 2. By construction, $\theta_3 < \theta_2 < \theta_1$. First, consider the customers in $[\theta_2, 1+b]$. For customer $\theta > \theta_1$, product 1's true value is at least $\theta q_1 - p_1$ (in case of poor match), which exceeds product 2's reservation price, $\theta q_2 - p_2 + a_2$. By Weitzman's stopping rule, she will end her search and purchase product 1. If customer $\theta \in [\theta_2, \theta_1]$ realizes a good match with product 1, she will stop search and purchase it, since its true value exceeds product 2's reservation price ($\theta q_1 + r - p_1 > \theta q_1 + a_1 - p_1 \geq \theta q_2 + a_2 - p_2$ for $\theta \in [\theta_2, \theta_1]$). Otherwise, she will continue to sample product 2 as the latter's reservation price exceeds product 1's realized value ($\theta q_2 + a_2 - p_2 \geq \theta q_1 - p_1$ for $\theta < \theta_1$). If product 2 yields a good match, she will purchase it. If product 2 is also a poor match, she will buy product 1 if $\theta q_1 - p_1 \geq \theta q_2 - p_2$ or equivalently if $\theta \geq (p_1 - p_2)/(q_1 - q_2)$ and will purchase product 2 otherwise.

Next, consider the customers in $[b, \theta_2]$. For customer $\theta < \theta_3$, product 2's true value is at least $\theta q_2 - p_2$ (in the case of poor match), which exceeds product 1's reservation price, $\theta q_1 - p_1 + a_1$. Therefore, she will end search and purchase product 2. If customer $\theta \in [\theta_3, \theta_2]$ realizes a good match after sampling 2, she will stop search and purchase it, since its realized value exceeds product 1's reservation price ($\theta q_2 + r - p_2 > \theta q_2 + a_2 - p_2 \geq \theta q_1 + a_1 - p_1$ for $\theta < \theta_2$). Otherwise, she will proceed to sample product 1 since product 1's reservation price exceeds product 2's realized value ($\theta q_1 + a_1 - p_1 > \theta q_2 - p_2$ for $\theta > \theta_3$). If product 1 yields a good match, she will purchase it. If product 1 is also a bad match, she will buy product 1 if $\theta \geq (p_1 - p_2)/(q_1 - q_2)$ and will purchase product 2 otherwise.

Figure 2 The Optimal Decision Rule of Intermediate Customers



In the text, we focus on the general pattern of segmentation where $\theta_3 > b$ and $\theta_1 < 1+b$, as illustrated in Figure 1. (Below, we identify the parameter conditions for such segmentation to hold in equilibrium.) The analysis of the degenerate case where $\theta_3 \leq b$ and $\theta_1 \geq 1+b$ is postponed to the online appendix.[12] Figure 2 illustrates the optimal search rule of customers in $[\theta_3, \theta_1]$.

3.2. Price Competition in Stage Two

We first examine the stage-2 price competition for given product qualities (q_i) and CLIs (k_i). From the customers' optimal search rule above, we can formulate firm i's demand D_i as

$$D_1 = (1+b-\theta_1) + \lambda(\theta_1 - \theta_2) + (1-\lambda)^2\left(\theta_1 - \frac{p_1 - p_2}{q_1 - q_2}\right) + \lambda(1-\lambda)(\theta_2 - \theta_3), \tag{6}$$

and

$$D_2 = (\theta_3 - b) + \lambda(\theta_2 - \theta_3) + (1-\lambda)^2\left(\frac{p_1 - p_2}{q_1 - q_2} - \theta_3\right) + \lambda(1-\lambda)(\theta_1 - \theta_2). \tag{7}$$

[11] The binary value distribution renders a relatively simple characterization of reservation price (R_i) and each firm's demand. A more general distribution may complicate the analysis. For example, suppose $v = r_1$ with probability λ_1, $v = r_2$ with probability λ_2 and $v = 0$ with probability $1 - \lambda_1 - \lambda_2$, where $r_1 > r_2 > 0$. Then, whether R_i is above or below $\theta q_i - p_i + r_2$ depends on the value of λ_1 ($R_i \geq \theta q_i - p_i + r_2 \Leftrightarrow \lambda_1 \geq (1-k_i)s/(r_1 - r_2)$). However, in the case where $R_i \geq \theta q_i - p_i + r_2$, the subsequent analysis remains intact as with a binary distribution.

[12] There still exist two other degenerate cases of segmentation: (1) $\theta_3 < b$ and $\theta_1 < 1+b$, and (2) $\theta_3 > b$ and $\theta_1 > 1+b$. We will not present these cases as they do not add any new insights.

In the expression of D_1, $(1+b-\theta_1)$ is the customers in $[\theta_1, 1+b]$ who purchase product 1 after sampling it. The second term, $\lambda(\theta_1-\theta_2)$, is the customers in (θ_2, θ_1) who realize a good match with product 1 and hence purchase it. The third term, $(1-\lambda)^2(\theta_1-(p_1-p_2)/(q_1-q_2))$, is the customers in $((p_1-p_2)/(q_1-q_2), \theta_1)$ who purchase product 1 after realizing a poor match with both products. The fourth term $(\lambda(1-\lambda)(\theta_2-\theta_3))$ is the customers in (θ_3, θ_2) who realize a poor match with product 2, proceed to sample product 1 and realize a good match. They then purchase product 1. The terms of D_2 have analogous interpretations.

Substituting for θ_i (from (3)–(5)) and noting that $\lambda(a_1-a_2)=s(k_1-k_2)$, we rewrite the demand functions as

$$D_1 = 1+b-\frac{p_1-p_2}{q_1-q_2}+\frac{s(k_1-k_2)}{q_1-q_2}, \tag{8}$$

and

$$D_2 = \frac{p_1-p_2}{q_1-q_2}-b-\frac{s(k_1-k_2)}{q_1-q_2}. \tag{9}$$

The effect of CLI on demand reallocation is then immediate: *By investing more than the competitor, firm i increases its own demand (at the expense of firm j) by $s(k_i-k_j)/(q_1-q_2)$, relative to when neither firm invests in customer learning, for $i, j=1,2$, $i\neq j$.* The reason is as follows: Customers in $(\theta_2, 1+b]$ (in the number of $1+b-(p_1-p_2-(a_1-a_2))/(q_1-q_2))$ will first sample product 1, and customers in $[b, \theta_2]$ (in the number of $(p_1-p_2-(a_1-a_2))/(q_1-q_2)-b$) will first sample product 2. When product i is easier to evaluate than j ($a_i > a_j$), more customers will first sample i, increasing the demand for i. Because the market is covered, the demand for j decreases. We call such demand reallocation the *competition effect* of CLI. Equal investments imply equal ease of evaluation and thus do not affect the firms' demand.

Each firm i chooses price p_i to maximize its revenue $R_i = D_i(p_i-c_i)$, where $c_i\equiv c(q_i)$ without confusion. The second-order conditions are clearly satisfied, and the first-order conditions lead to a unique price equilibrium

$$p_1^* = \frac{1}{3}[(2+b)(q_1-q_2)+s(k_1-k_2)+2c_1+c_2], \tag{10}$$

and

$$p_2^* = \frac{1}{3}[(1-b)(q_1-q_2)-s(k_1-k_2)+c_1+2c_2]. \tag{11}$$

Note that $p_1^* > p_2^*$ when r is sufficiently low (which implies s is low as $s\leq\lambda(1-\lambda)r$ by assumption). We can verify that $\theta_3 > b$ and $\theta_1 < 1+b$ when $r<\min\{((1-b)\cdot(q_1-q_2)+(c_1-c_2))/(3+2\lambda(1-\lambda)), ((2+b)(q_1-q_2)-(c_1-c_2))/(3+2\lambda(1-\lambda))\}$.[13] Provided the horizontal attribute is not too important, some of the customers will indeed purchase their preferred quality regardless of realized match. The market is covered if $bq_2-p_2^*\geq 2s$ or equivalently if $b\geq((q_1-q_2)-s(k_1-k_2)+c_1+2c_2+6s)/(q_1+2q_2)$. It is easy to verify that firm i's equilibrium demand is $D_i=(p_i^*-c_i)/(q_1-q_2)$ and its revenue $R_i=(p_i^*-c_i)^2/(q_1-q_2)$. To better demonstrate the impacts of CLI, we will frequently compare with the equilibrium where neither firm invests in customer learning (obtained by setting $k_1=k_2=0$). Proposition 1 follows.

Proposition 1 (Effects of CLI on Pricing). *Suppose the firms' qualities q_i and CLIs k_i are exogenously given. When they choose different CLIs, the equilibrium demand and price (and hence revenue) of the firm with a larger CLI are higher and those of the competitor are lower than when neither firm invests in customer learning. When they choose equal CLIs, each firm's demand and price remain the same as when neither firm invests in customer learning.*

When the firms make equal investments, their products are equally costly to evaluate (just as when neither firm invests in customer learning), and thus their demand and prices remain intact. However, asymmetric CLIs always increase the demand and price of the firm making a larger CLI but decrease those of the other, relative to when neither firm invests. Consequently, the differences between the firms' market shares and prices enlarge when the high-end firm invests more, and shrink when the low-end firm invests more. Therefore, through making a greater CLI than the competitor the high-end firm reinforces its competitive advantage and the low-end firm alleviates its competitive disadvantage.

3.3. Competition in Quality and CLI in Stage One

To show the strategic interplay between product quality and CLI, we now turn to the stage-one game

[13] Because $0\leq k_i<1$ by assumption, we have $-1<k_1-k_2<1$. We then have

$$\begin{aligned} p_1^*-p_2^*-a_1 &> p_1^*-p_2^*-r \\ &= \tfrac{1}{3}[(1+2b)(q_1-q_2)+(c_1-c_2)+2s(k_1-k_2)-3r] \\ &> \tfrac{1}{3}[(1+2b)(q_1-q_2)+(c_1-c_2)-2s-3r] \\ &> \tfrac{1}{3}[(1+2b)(q_1-q_2)+(c_1-c_2)-2\lambda(1-\lambda)r-3r]. \end{aligned}$$

Here the first inequality is due to $a_i<r$ by construction, the second due to $k_1-k_2>-1$, and the third due to $s<\lambda(1-\lambda)r$ by assumption. It is easy to verify that $\theta_3=(p_1^*-p_2^*-a_1)/(q_1-q_2)>b$ when $r<((1-b)(q_1-q_2)+(c_1-c_2))/(3+2\lambda(1-\lambda))$.

Similarly, we can show that $\theta_1=(p_1^*-p_2^*+a_2)/(q_1-q_2)<1+b$ when $r<((2+b)(q_1-q_2)-(c_1-c_2))/(3+2\lambda(1-\lambda))$.

where the firms simultaneously choose and commit to q_i and k_i to maximize their profits, anticipating the subsequent price equilibrium. Their stage-1 objective functions are

$$\pi_1 = \frac{1}{9(q_1 - q_2)}[(2+b)(q_1 - q_2) - (c_1 - c_2) + s(k_1 - k_2)]^2 - h(k_1), \quad (12)$$

and

$$\pi_2 = \frac{1}{9(q_1 - q_2)}[(1-b)(q_1 - q_2) + (c_1 - c_2) - s(k_1 - k_2)]^2 - h(k_2). \quad (13)$$

Any subgame perfect equilibrium (SPE) must be jointly characterized by the firms' first order conditions (FOCs) w.r.t. k_i and q_i (given in the proof of Proposition 2 in the appendix). Proposition 2 identifies its basic properties.

Proposition 2. *In equilibrium*: (A) *The firms' CLIs satisfy* $h'(k_1^*) + h'(k_2^*) = 2s/3$ *and their qualities satisfy* $c'(q_1^*) - c'(q_2^*) = \frac{3}{2}$; (B) *As technologies evolve, firm* 1, *the high-end firm, will adjust its quality and CLI in opposite directions. Firm* 2 *will adjust its quality and CLI in the same direction.*

That $h'(k_1^*) + h'(k_2^*) = 2s/3$ implies that the firms' total investments cannot be too high. When h is fixed, changes in production technology (c) will cause the firms' CLIs to move in opposite directions. When $h(k) = \beta k^2$, we have $k_1^* + k_2^* = s/(3\beta)$. That $c'(q_1^*) - c'(q_2^*) = \frac{3}{2}$ reflects the degree of quality differentiation. When c is fixed, changes in customer learning technology (h) will cause the firms' qualities to move in the same direction. When $c(q) = \alpha q^2$, we have $q_1^* - q_2^* = 3/(4\alpha)$. The intuition for part (B) of Proposition 2 is that each firm wishes to expand its demand through lowering its product's evaluation cost. When the market is covered, the only way for the high-end (low-end) firm to increase its demand is to acquire additional customers with progressively lower (higher) valuation for quality.

Let q_i^N denote firm i's equilibrium quality when neither firm invests in customer learning.[14] The next two propositions provide our core results.

Proposition 3 (Effects of CLI on Quality Choices). *Compared with when neither firm invests in customer learning*: (A) *If the equilibrium involves a positive correlation between CLI and quality, both firms' qualities decrease*; (B) *If the equilibrium involves a negative correlation between CLI and quality, both firms' qualities increase*; *and* (C) *Otherwise, both qualities remain unchanged.*

[14] Note that q_1^N and q_2^N are jointly given by the firms' FOCs w.r.t. q_i (see the proof of Proposition 2 in the appendix) after setting $k_1 = k_2 = 0$.

This proposition shows the possible impacts of CLI competition on the firms' quality choices. When the high-end (low-end) firm invests more in customer learning, both qualities will decrease (increase) relative to when neither firm invests. The firms' qualities remain intact with symmetric investments. Proposition 3 is rather strong as it does not depend on the production (c) or customer learning (h) technologies.

The rationale behind this is that *the firms' relative investments in customer learning drive their demand elasticities of quality*. Substituting p_1^* and p_2^* into (8) and (9) yields the firms' stage-one demand functions, which lead to[15]

$$\frac{\partial D_1}{\partial q_1} = \frac{-1}{3(q_1 - q_2)} \cdot \left[c'(q_1) - \frac{c(q_1) - c(q_2)}{q_1 - q_2} + \frac{s(k_1 - k_2)}{q_1 - q_2}\right], \quad (14)$$

and

$$\frac{\partial D_2}{\partial q_2} = \frac{1}{3(q_1 - q_2)} \cdot \left[\frac{c(q_1) - c(q_2)}{q_1 - q_2} - c'(q_2) - \frac{s(k_1 - k_2)}{q_1 - q_2}\right]. \quad (15)$$

Note that $c'(q_1) > (c(q_1) - c(q_2))/(q_1 - q_2) > c'(q_2)$, since c is increasing and convex by assumption. When neither firm invests in CLI ($k_1 = k_2 = 0$), we have $\partial D_1/\partial q_1 < 0$ and $\partial D_2/\partial q_2 > 0$. This implies that to expand its demand firm 1 (2) needs to lower (raise) its quality. When $k_1 > k_2$, D_1 becomes more elastic in q_1 and D_2 is less elastic in q_2 than when neither firm invests. This causes both firms to lower their qualities. When $k_1 < k_2$, D_1 is less elastic in q_1 and D_2 is more elastic in q_2 than when neither firm invests. Therefore, both firms will raise their product qualities.

Let $\hat{q}_1$ and $\hat{q}_2$ be uniquely given by $c'(\hat{q}_1) = \frac{5}{4} + b$ and $c'(\hat{q}_2) = -\frac{1}{4} + b$. In equilibrium, the firms choose equal CLIs if and only if the two qualities are $\hat{q}_1$ and $\hat{q}_2$.

Proposition 4 (Effects of Quality on CLI Choices). *In equilibrium*: (A) *When the product qualities are low* (*in that* $q_1^* < \hat{q}_1$ *and* $q_2^* < \hat{q}_2$), *the high-end firm, firm* 1, *invests more in customer learning*;[16] (B) *When the product qualities are high* (*in that* $q_1^* > \hat{q}_1$ *and* $q_2^* > \hat{q}_2$), *the low-end firm, firm* 2, *invests more in customer learning*; *and* (C) *Otherwise* (*in that* $q_1^* = \hat{q}_1$ *and* $q_2^* = \hat{q}_2$), *the firms invest equally in customer learning.*

[15] Firms 1 and 2's stage-one demand functions are $D_1 = \frac{1}{3}[(2+b) + (s(k_1 - k_2) - (c(q_1) - c(q_2)))/(q_1 - q_2)]$ and $D_2 = \frac{1}{3}[(1-b) - (s(k_1 - k_2) - (c(q_1) - c(q_2)))/(q_1 - q_2)]$, respectively.

[16] As Proposition 2 shows, $c'(q_1^*) - c'(q_2^*) = \frac{3}{2}$ in equilibrium. Therefore, $q_1^* < \hat{q}_1$ and $q_2^* < \hat{q}_2$ hold simultaneously.

The essence of Proposition 4 is that *the firm with a greater relative production efficiency invests more in customer learning*. Intuitively, which firm invests more in customer learning comes down to their relative production efficiency. Note that c is convex by assumption and that $c'(q_1^*) - c'(q_2^*) = \frac{3}{2}$ (from Proposition 2). When the products' qualities are low ($q_1^* < \hat{q}_1$ and $q_2^* < \hat{q}_2$), their cost difference is small relative to their quality difference, so that $(c(q_1^*) - c(q_2^*))/(q_1^* - q_2^*) < (c(\hat{q}_1) - c(\hat{q}_2))/(\hat{q}_1 - \hat{q}_2)$ (Figure 3(a)). In this case, the high-end firm has a higher relative production efficiency, as its quality advantage dominates its unit cost disadvantage. This enables the high-end firm to capture a higher marginal return from CLI, and it thus invests more aggressively in customer learning than the low-end firm. When the products' qualities are high ($q_1^* > \hat{q}_1$ and $q_2^* > \hat{q}_2$), their cost difference is large relative to their quality difference, so that $(c(q_1^*) - c(q_2^*))/(q_1^* - q_2^*) > (c(\hat{q}_1) - c(\hat{q}_2))/(\hat{q}_1 - \hat{q}_2)$ (Figure 3(b)). In this case, the low-end firm has a higher relative production efficiency and reaps a higher marginal return from CLI. It then invests more in customer learning than the high-end firm.

To further clarify the above analysis, we provide two examples.

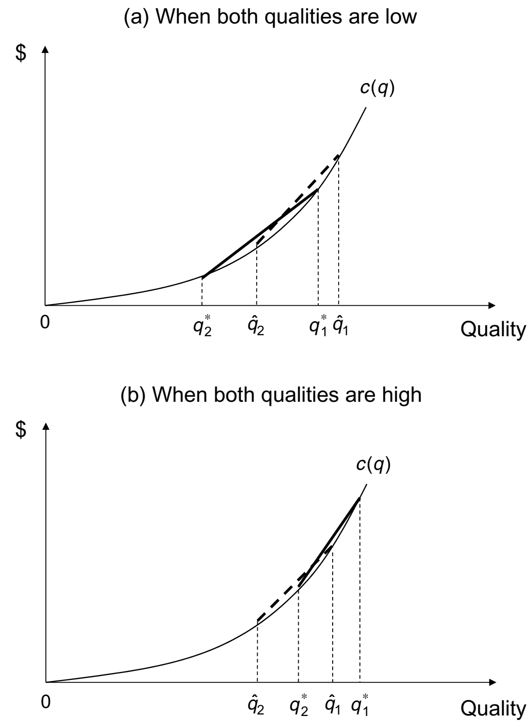
Example 1. Suppose $h(k) = \beta k^2$ and $c(q) = \alpha q^2$, with $\beta > s/6$ and $\alpha > 0$. The unique SPE then follows from the firms' FOCs: $k_1^* = k_2^* = s/(6\beta)$, $q_1^* = (5 + 4b)/(8\alpha)$ and $q_2^* = (-1 + 4b)/(8\alpha)$. When neither firm invests in customer learning, the unique quality equilibrium is $q_1^N = q_1^*$ and $q_2^N = q_2^*$. Propositions 3 and 4 clearly hold in this example.

Example 2. Suppose $h(k) = \beta k^3$ and $c(q) = \alpha q^2$, with $\alpha > 9/(16s)$ and $32\alpha s^2/81 < \beta < 2s(16\alpha s)^2/(27)^2$. When neither firm invests in customer learning, $q_1^N = (5 + 4b)/(8\alpha)$ and $q_2^N = (-1 + 4b)/(8\alpha)$. Let $A \equiv 32\alpha s^2/(81\beta)$ and $B \equiv 2s/(9\beta)$. From the firms' FOCs, we obtain two SPEs: (1) $k_1^* = (A + \sqrt{2B - A^2})/2$, $k_2^* = (A - \sqrt{2B - A^2})/2$, $q_1^* = (1/(4\alpha))[(5 + 4b)/2 - (3A/(2B))\sqrt{2B - A^2}] < q_1^N$, $q_2^* = (1/(4\alpha))[(-1 + 4b)/2 - (3A/(2B))\sqrt{2B - A^2}] < q_2^N$; (2) $k_1^* = (A - \sqrt{2B - A^2})/2$, $k_2^* = (A + \sqrt{2B - A^2})/2$, $q_1^* = (1/(4\alpha))[(5 + 4b)/2 + (3A/(2B))\sqrt{2B - A^2}] > q_1^N$, $q_2^* = (1/(4\alpha))[(-1 + 4b)/2 + (3A/(2B))\sqrt{2B - A^2}] > q_2^N$. When $32\alpha s^2/81 < \beta < 2s(16\alpha s)^2/(27)^2$, we have $0 < k_i < 1$ $(i = 1, 2)$. It is easy to see that Propositions 3 and 4 hold in each of the two SPEs.

3.4. Two Special Cases

3.4.1. CLI Competition with Exogenous Product Qualities. To better show how the firms' quality-cost positions drive their CLIs, we now examine a stage-one game wherein the firms only endogenize CLIs, with product qualities exogenously fixed: $q_1 > q_2$. In practice, many complex products are sold through intermediaries (e.g., dealers and retailers) who allocate resources to ease product evaluation but lack direct control over product quality.

Figure 3 The Firms' Relative Production Efficiency



Observing each other's quality levels, the firms simultaneously choose and commit to CLI k_i, anticipating the stage-2 price equilibrium above. For tractability, here we assume $h(k) = \beta k^2$, with $\beta > 0$. The firms' stage-one profit functions are given in (12) and (13). The unique SPE then follows from the FOCs w.r.t. k_i:

$$k_1^* = \frac{1}{2}\left[\frac{1}{3\beta} + \frac{(1+2b)(q_1 - q_2) - 2(c_1 - c_2)}{9\beta(q_1 - q_2) - 2s^2}\right]s, \tag{16}$$

and

$$k_2^* = \frac{1}{2}\left[\frac{1}{3\beta} - \frac{(1+2b)(q_1 - q_2) - 2(c_1 - c_2)}{9\beta(q_1 - q_2) - 2s^2}\right]s. \tag{17}$$

In equilibrium, the market is covered if $bq_2 - p_2^* \ge 0$. When $\beta > 2s^2/(9(q_1 - q_2))$, $(k_1^* - k_2^*)$ increases in b and hence p_2^* (see (11)) decreases in b. Therefore, $bq_2 - p_2^* \ge 0$ holds when b is not too small. We can easily verify that $\theta_1 < 1 + b$ holds when β is sufficiently large and when r is not too high, and that $\theta_3 > b$ holds when b and r are not too high.

Proposition 5. *Suppose the firms' qualities q_1 and q_2 are exogenously fixed, $q_1 > q_2$ and $h(k) = \beta k^2$, where $\beta > 2s^2/(9(q_1 - q_2))$. (A) When $(c_1 - c_2)/(q_1 - q_2) \le (1 + 2b)/2$, firm 1 invests more than firm 2 in customer learning.*

Firm 2's profits are lower than those when neither firm invests. (B) *When* $(c_1 - c_2)/(q_1 - q_2) > (1+2b)/2$, *firm* 2 *invests more than firm* 1 *in customer learning. Firm* 1*'s profits are lower than those when neither firm invests.*

Note that $(1+2b)/2 = ((1+b)+b)/2$ is the mean (marginal) valuation for quality in this market. When the products' unit cost difference is lower than their utility difference for the average customer ($c_1 - c_2 \le ((1+2b)(q_1-q_2))/2$), firm 1, the high-end firm, invests more in customer learning than firm 2. Firm 2 invests more otherwise. Proposition 5 is thus consistent with Proposition 4 in spirit: *The more efficient firm invests more in customer learning*. In either case, the firm investing less is strictly worse off than when neither firm invests, reflecting the competition effect of CLI. Proposition 5 is also consistent with the finding of Gu and Xie (2013) that when marginal production cost is constant over quality, the high-end firm has a stronger incentive to provide matching information than the low-end firm.

The intuition behind part (A) of Proposition 5 is as follows: When $(c_1 - c_2)/(q_1 - q_2) \le (1+2b)/2$, if the firms were to invest equally in customer learning, firm 1 would enjoy a higher marginal return from CLI than firm 2.[17] This would induce firms 1 and 2 to increase and decrease their CLIs, respectively. The intuition for part (B) is analogous. Part (A) of Proposition 5 resonates with the following observation: In industries where unit production costs do not increase significantly with quality (e.g., software, pharmaceuticals, and consumer electronics), firms with higher qualities often invest markedly more in customer learning (in the form of demonstration, detailing, and setting up experience centers, etc.) than their low-end counterparts.

3.4.2. Quality Competition with Exogenous CLIs. In industries where new products are released at a rapid pace (such as consumer electronics and digital devices), firms' investments in experience centers and sales efforts are often fixed well before the next generation products are developed. To gauge how the firms' exogenous CLIs affect quality competition in such scenarios, we now analyze a stage-one game wherein they compete only in quality. Specifically, we assume $c(q) = \alpha q^2$, where $\alpha > 0$. The firms' stage-one objective functions are given by (12) and (13), with $c(q_i) = \alpha q_i^2$ and $h(k_i) = 0$. We easily derive a unique equilibrium

$$q_1^* = \frac{5+4b}{8\alpha} - \frac{2s(k_1-k_2)}{3}, \tag{18}$$

and

$$q_2^* = \frac{-1+4b}{8\alpha} - \frac{2s(k_1-k_2)}{3}. \tag{19}$$

The market is covered if $bq_2^* - p_2^* \ge 0$, which holds when b is sufficiently large. We can easily verify that $\theta_3 > b$ and $\theta_1 < 1+b$ hold when $3a_1 - 9/(8\alpha) < s(k_1-k_2) < -3a_2 + 9/(8\alpha)$. When neither firm invests in customer learning, the unique SPE is $q_1^N = (5+4b)/(8\alpha)$ and $q_2^N = (-1+4b)/(8\alpha)$. Proposition 3 clearly holds.

4. Extensions

4.1. Sequential Choice of CLI and Quality in the Market-Not-Covered Duopoly

Our baseline model considers a market-covered duopoly where the firms simultaneously choose product quality and CLI before competing in price. However, in industries with relatively short product life cycles (e.g., digital devices), firms sometimes invest in customer learning (e.g., setting up experience centers) before deciding on the quality of future generation products.[18] Therefore, to account for such scenarios we now examine a three-stage game wherein the firms choose CLI (k_i) in stage 1, quality (q_i) in stage 2, and price (p_i) in stage 3. In each stage, the firms observe each other's decisions in prior stages (if any) and act simultaneously. We analyze the market-not-covered case below and the market-covered case in §4.2. For tractability, in both cases we assume that $c(q) = 0$ for $q \in [q_L, q_H]$, where $0 < q_L < q_H$, and $h(k) = \phi k$ for $k \in [0, \bar{k}]$, where $\phi > 0$ and $0 < \bar{k} < 1$.[19] Again, suppose firm 1 chooses an equal or higher quality.

When b is sufficiently close to zero, the customers with very low preference for quality do not purchase either good. We continue to focus on the scenario wherein some of the customers purchase their favorite products regardless of realized match. Clearly, the optimal decision rules of the customers in $[\theta_3, 1+b]$ remain identical to that in §3.1. To characterize optimal search by the remaining customers, we let

$$\theta_4 = \frac{p_2}{q_2} \quad \text{and} \quad \theta_5 = \frac{p_2 - a_2}{q_2}. \tag{20}$$

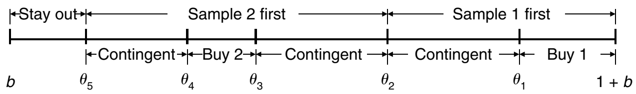
For the customers in $[\theta_4, \theta_3]$, the realized value of product 2 (even with a poor match) always exceeds

[17] If $k_1 = k_2$, firm 1's marginal return from CLI is $(2s/(9(q_1-q_2))) \cdot [(2+b)(q_1-q_2) - (c_1-c_2)]$, and that of firm 2 is $(2s/9(q_1-q_2))[(1-b)\cdot(q_1-q_2) + (c_1-c_2)]$. When $(c_1-c_2)/(q_1-q_2) \le (1+2b)/2$, the former dominates the latter.

[18] We thank an anonymous reviewer for this observation.

[19] Clearly, analysis of the three-stage game is not tractable with general production and customer-learning technologies because formulating the firms' stage-1 objectives requires explicit values of equilibrium product qualities in stage 2. With a general production technology, the stage-2 quality equilibrium can best be characterized with the firms' FOCs.

Figure 4 Segmentation in the Market-Not-Covered Duopoly



the reservation price of product 1, i.e., $\theta q_2 - p_2 \geq 0$ ($\Leftrightarrow \theta \geq \theta_4$) and $\theta q_2 - p_2 > \theta q_1 + a_1 - p_1$ ($\Leftrightarrow \theta < \theta_3$). Therefore, these customers will purchase product 2 regardless of realized match. The customers in $[\theta_5, \theta_4)$ will sample product 2 and will purchase it only if it is a good match ($\lambda(\theta q_2 + r - p_2) + (1-\lambda)0 - (1-k_2)s \geq 0 \Leftrightarrow \theta q_2 + a_2 - p_2 \geq 0$). Note that when $\theta_3 > \theta_4$, a customer in $[\theta_5, \theta_4)$ never samples product 1.[20] Figure 4 depicts the pattern of market segmentation.

The demand function of product 1, D_1, remains the same as in (8). The demand function of product 2 now becomes

$$\begin{aligned} D_2 &= \lambda(1-\lambda)(\theta_1 - \theta_2) + \lambda(\theta_2 - \theta_3) \\ &\quad + (1-\lambda)^2\left(\frac{p_1 - p_2}{q_1 - q_2} - \theta_3\right) + (\theta_3 - \theta_4) + \lambda(\theta_4 - \theta_5) \\ &= \frac{p_1 - p_2}{q_1 - q_2} - \frac{s(k_1 - k_2)}{q_1 - q_2} + \frac{\lambda a_2 - p_2}{q_2}, \end{aligned} \tag{21}$$

where the second equality is obtained after collecting terms and using $a_i = r - (1-k_i)s/\lambda$.

The competition effect of CLI persists; either firm may increase its demand by investing more than its competitor in customer learning. Besides, CLI by firm 2 (the low-end firm) also creates a *market-expansion effect* through inducing more low-end customers to sample (and purchase in case of a good match) its product. This is clear since θ_5 decreases in k_2.

In the third stage, the firms observe each other's CLI k_i and quality q_i and set prices p_i simultaneously to maximize their own revenue, $R_i = D_i p_i$. The unique price equilibrium readily follows from the FOCs:

$$p_1^* = \frac{1}{4q_1 - q_2} \cdot [2(1+b)q_1(q_1 - q_2) + (2q_1 - q_2)\lambda a_1 - q_1 \lambda a_2], \tag{22}$$

and

$$p_2^* = \frac{1}{4q_1 - q_2} \cdot [(1+b)q_2(q_1 - q_2) - q_2 \lambda a_1 + (2q_1 - q_2)\lambda a_2]. \tag{23}$$

When r is sufficiently low, a_i is low (regardless of the firms' CLIs) and $p_1^* > p_2^*$ always holds.

[20] When $\theta_3 > \theta_4$, θ_4 will not sample product 1, as $\lambda(\theta_4 q_1 + r - p_1) + (1-\lambda)0 - (1-k_1)s < 0 \Leftrightarrow p_1 q_2 - p_2 q_1 > q_2 a_1$, which holds when $\theta_3 > \theta_4$.

Proposition 6. *Suppose $q_1 > q_2$. Firm 1's price is higher (lower) than when neither firm invests in customer learning if $k_1/k_2 \geq (<) q_1/(2q_1 - q_2)$. Firm 2's price is higher (lower) than when neither firm invests in customer learning if $k_1/k_2 \leq (>) (2q_1 - q_2)/q_2$.*

Proposition 6 contrasts with Proposition 1. In the market-covered duopoly, compared with when neither firm invests in customer learning, the prices remain unchanged under symmetric CLIs and move in opposite directions otherwise. When the market is not covered, both prices increase when the difference between their CLIs is relatively small ($q_1/(2q_1 - q_2) < k_1/k_2 < (2q_1 - q_2)/q_2$). *In particular, with symmetric CLIs both prices will increase.* The intuition is that symmetric CLIs do not directly affect the high-end firm's demand, but increases the low-end firm's demand due to the market-expansion effect, thus relaxing price rivalry. The equilibrium revenues are $R_1 = (p_1^*)^2/(q_1 - q_2)$ and $R_2 = q_1(p_2^*)^2/(q_2(q_1 - q_2))$.

We now turn to the stage-2 quality competition. For the remainder of this subsection, we assume $q_L \geq \frac{4}{7}q_H$, so that the feasible range of quality is not too broad. *When s is not too high, the unique quality equilibrium involves maximum differentiation, i.e., $q_1 = q_H$ and $q_2 = q_L$, regardless of the firms' stage-1 CLI decisions* (see the online appendix for deduction). The intuition behind this is as follows: Because the unit cost is constant (normalized to zero) over quality, firm 1, the high-end firm, naturally chooses the highest feasible quality. However, the low-end firm faces a trade-off in its quality choice. Choosing a lower quality helps mitigate the ensuing price rivalry, whereas choosing a higher quality increases its product's market appeal and hence demand. When the quality space is sufficiently narrow ($q_L \geq \frac{4}{7}q_H$), the former motive dominates the latter, leading to maximum differentiation.

In stage 1, the firms choose CLI k_i. Firm i's period-1 objective function is $\pi_i = R_i(q_1 = q_H, q_2 = q_L) - \phi k_i$.

Proposition 7. *Suppose $q_L \geq \frac{4}{7}q_H$ and s is sufficiently low. In the unique SPE, $q_1 = q_H$ and $q_2 = q_L$.* (A) *When the marginal cost of CLI (ϕ) is very low, both firms choose the maximum CLI, $\bar{k}$.* (B) *When ϕ is intermediate and the expected match value is relatively high, firm 2, the low-end firm, invests $\bar{k}$ and firm 1 does not invest in customer learning.* (C) *When ϕ is intermediate and the expected match value is relatively low, firm 1, the high-end firm, invests $\bar{k}$ and firm 2 does not invest in customer learning.* (D) *When ϕ is sufficiently high, neither firm invests in customer learning.*[21]

Because each firm i's profit function is convex in k_i, k_i can only possibly take the extreme values

[21] A restatement of Propositions 7 and 8 in the online appendix provides the exact conditions.

of 0 and $\bar{k}$. Not surprisingly, both firms invest the maximum amount $\bar{k}$ when the marginal cost of CLI (ϕ) is sufficiently low (part (A)), and neither firm invests when ϕ is very high (part (D)). Asymmetric CLIs emerge for intermediate values of ϕ. When the expected match value is relatively high, the low-quality firm invests $\bar{k}$ but the high-quality firm does not invest (part (B)). When the expected match value is relatively low, the opposite CLI pattern occurs (part (C)).

The intuition behind parts (B) and (C) is as follows: An important horizontal attribute (as in part (B)) strengthens the market-expansion effect of CLI, which prompts the low-end firm to invest more aggressively. The outcome is as if the firms differentiate by specializing in different attributes: One firm does not invest in customer learning but chooses a high quality, whereas the other chooses the maximum CLI but a low quality. On the other hand, a relatively unimportant horizontal attribute (part (C)) weakens the market-expansion effect of CLI, which curtails the low-end firm's incentive to invest. In this case, the high-end firm strengthens its competitive advantage by investing more in customer learning.

4.2. Sequential Choice of CLI and Quality in the Market-Covered Duopoly

To highlight the market-expansion effect of CLI in the market-not-covered duopoly, we examine the three-stage CLI-quality-price game in the market-covered duopoly.

Proposition 8. *There is a unique SPE in the market-covered duopoly, where $q_1 = q_H$ and $q_2 = q_L$.* (A) *When the marginal cost of quality (ϕ) is low, both firms choose the maximum CLI, $\bar{k}$.* (B) *When ϕ is intermediate, firm* 1, *the high-end firm, invests $\bar{k}$ and firm* 2 *does not invest.* (C) *When ϕ is sufficiently high, neither firm invests in customer learning.* (D) *The low-quality firm (firm* 2) *never invests more than the high-quality firm in customer learning.*

Just as in the market-not-covered duopoly, both firms invest the maximum amount $\bar{k}$ when ϕ is very low (part (A)) and will not invest at all when ϕ is very high (part (C)). When ϕ takes intermediate values (as in part (B)), the high-quality firm invests $\bar{k}$ whereas the low-quality firm does not invest at all in customer learning.

The high-end firm always invests equal or greater amounts in customer learning than the low-quality firm (part (D)), which contrasts with Proposition 7. In the market-not-covered duopoly, the market-expansion effect may prompt the low-quality firm to choose a strictly higher CLI than its rival to mitigate its competitive disadvantage. When the market is fully covered, the market-expansion effect of CLI vanishes and the insight from Proposition 4 applies: The firm with a higher relative production efficiency (here, the high-quality firm) invests more in customer learning than its competitor.

4.3. The Effects of CLI on R&D

In the basic model, the firms face zero fixed production costs and constant unit variable costs that increase in quality. For software and certain high tech goods, however, product quality is primarily driven by a firm's R&D expenditure; unit variable costs need not increase with quality. We now consider this alternative cost structure and examine how the firms' CLIs affect their product qualities or R&D efforts. Suppose that the feasible quality space is $[\underline{q}, \infty)$, where $\underline{q} > 0$ is some minimum quality standard possibly imposed by regulation. The firms face an identical R&D technology under which the costs of devising a product of quality q is $g(q)$, with $g' > 0$ and $g'' > 0$. We assume that $g(0) = 0$, $g'(0) = 0$, and $\lim_{q\to\infty} g'(q) = \infty$, as in Lehmann-Grube (1997). Their common unit variable costs are constant and independent of quality, and are normalized to zero. We retain the rest of the set-up of the basic model and focus on the market-covered duopoly.

The subgame perfect equilibrium is derived in the online appendix, where we show that the low-end quality equals $\underline{q}$, the lowest admissible quality, regardless of whether the firms invest in customer learning. *The high-end quality is strictly lower than when neither firm invests in customer learning*. This is because at the price equilibrium the low-end firm's marginal revenue in own quality is always negative (with or without CLI) and because the firms' CLIs lower the high-end firms' marginal revenue in own quality.

5. Two Benchmarks

5.1. The Full-Information Duopoly

We now consider a special case of the baseline model wherein each customer costlessly observes her match values with both products. The game under full information is essentially a special case of the baseline model with $s = 0$.[22] The stage-2 price equilibrium is obtained with $s = 0$ in (10) and (11). The firms' stage-1 profit functions are given by (12) and (13) with $s = 0$. The quality equilibrium is then characterized by the FOCs: $2c'(q_1^F) = (2 + b) + (c(q_1^F) - c(q_2^F))/(q_1^F - q_2^F)$ and $2c'(q_2^F) = -(1 - b) + (c(q_1^F) - c(q_2^F))/(q_1^F - q_2^F)$. The equilibrium under full information is thus identical to that of our baseline model when neither firm invests in customer learning, q_1^N and q_2^N.

[22] There are λ^2 ($(1-\lambda)^2$) customers with a good (poor) match with both products, $\lambda(1-\lambda)$ customers with a good match with only product 1, and $\lambda(1-\lambda)$ customers with a good match with only product 2.

5.2. A Duopoly Without Quality Differentiation

Our main analysis has examined how CLI competition interacts with vertical differentiation. One may wonder about the strategic role of CLI in a setting with homogeneous quality. We now investigate a variant of the main model where the firms have an identical product quality, q_0 say. Because q_0 does not affect customer search, to ease exposition we normalize q_0 and the unit cost to zero.

Customers will sample product i only if $\lambda(r-p_i)+(1-\lambda)0-(1-k_i)s\geq 0$. Therefore, $R_i=a_i-p_i\geq 0$ $(i=1,2)$ in equilibrium. Suppose product i has a higher reservation price than j, i.e., $a_i-p_i>a_j-p_j\geq 0$ $(i,j=1,2,\ i\neq j)$. Then, all customers will first sample i, and will purchase i if it yields a good match (with probability λ). A customer who realizes a poor match (with probability $1-\lambda$) will proceed to sample j, and will purchase j if it yields a good match. Firm i's demand is thus λ and firm j's $\lambda(1-\lambda)$. This demand discontinuity implies that there is no pure-strategy equilibrium in the stage-2 pricing game.

Proposition 9. *Suppose the firms' CLIs satisfy $0\leq k_1\leq k_2<1$. The unique price equilibrium is in mixed strategies, and the firms' price distributions are*

$$F_1(p_1)=\frac{1}{\lambda}\left[1-\frac{a_2-\lambda a_1}{p_1-(a_1-a_2)}\right],\quad \textit{and}$$
$$F_2(p_2)=\frac{1}{\lambda}\left[1-\frac{(1-\lambda)a_1}{p_2+(a_1-a_2)}\right],$$

for $(1-\lambda)a_1\leq p_1\leq a_1$ and $a_2-\lambda a_1<p_2<a_2$. Firm 1's strategy has an atom at a_1. The equilibrium revenues are $R_1=\lambda(1-\lambda)a_1$ and $R_2=\lambda(a_2-\lambda a_1)$.

The price equilibrium when $k_1>k_2$ is obtained by invoking symmetry. By construction, the firm investing more in customer learning has a higher a_i. Proposition 9 shows that the firm with a greater CLI (here, firm 2) has more market power and collects higher revenue. Firm 2 prices more aggressively in that it prices below a_2 with probability one, whereas firm 1 places an atom at a_1.

We now turn to the stage-1 competition in CLI. Without loss of generality, suppose firm 2 chooses an equal or higher CLI than firm 1. By Proposition 9, firm 1's stage-1 profit function is $\pi_1(k_1)=(1-\lambda)(\lambda r-s+sk_1)-h(k_1)$ and firm 2's $\pi_2(k_2)=(\lambda r-s)-\lambda^2a_1+sk_2-h(k_2)$.

Proposition 10. (A) *The unique SPE in CLI (after suppressing the firms' identities) is one firm choosing k_L and the other k_H, where $(1-\lambda)s=h'(k_L)$ and $s=h'(k_H)$.* (B) *Both firms make higher profits than when neither firm invests in customer learning, and the firm choosing k_H gains more from CLI.*

Interestingly, *the ex ante symmetric firms always choose different levels of CLI.* The reason is that choosing different CLIs helps relax price rivalry. Without quality differentiation, the products are ex ante homogeneous. If the firms choose the same CLI, their products would have an identical a_i and, consequently, all customers would first sample the product with a lower price. This intensifies price rivalry as the firms have to compete on the basis of price alone.

The equilibrium CLIs are efficient provided there are no economies of scope in lowering the products' evaluation costs. To see this, a social planner offers both products at cost (normalized to zero) and minimizes the sum of customers' expected search costs and the CLI costs. The customers will first sample the product with a lower evaluation cost. In case of a poor match (with probability $1-\lambda$), she proceeds to sample the other product. Suppose product 2 has a (weakly) lower evaluation cost. Without any spillover effects in lowering the products' evaluation costs, the social planner chooses k_2 and k_1 to minimize $(1-k_2)s+h(k_2)+(1-\lambda)(1-k_1)s+h(k_1)$. Clearly, the efficient CLIs are k_H and k_L.

Somewhat surprisingly, CLI competition does not lead to a prisoner's dilemma, but instead increases both firms' profits. This is because prices are set *before* customers search in our model. When neither firm invests in customer learning, evaluation cost is high (at s) and firms must price sufficiently low (at or below $a_0=r-s/\lambda$) to induce search. Through lowering evaluation costs, CLI allows the firms to raise prices while attracting customers to search, which leads to higher profits.

6. Conclusion

When resolution of match uncertainty requires costly evaluation, the first product sampled by the customer is more likely to make the sale. All else equal, customers will first sample the product with a lower evaluation cost. Therefore, firms invest strategically to ease product evaluation. In a duopoly, we have shown that such CLI has a significant impact on quality and price competition.

In a market-covered duopoly, CLI demonstrates a *competition effect*: By investing more than the competitor in customer learning, a firm increases its demand at the expense of the competitor. For given product qualities, the price of the firm with a greater CLI increases whereas the competitor's decreases relative to when neither firm invests. When the firms endogenize product quality and CLI, both qualities will decrease when the high-end firm invests more, increase when the low-end firm invests more, and remain unchanged when they invest equally, relative to when neither firm invests. The high-end firm invests more in customer learning than the low-end firm when the former has a higher relative production efficiency, and the low-end firm invests more otherwise. In a market-not-covered duopoly, CLI by the low-end firm further introduces a *market-expansion effect*; some of the low-end customers who would not sample either product without CLI will now sample the low-end product. Interestingly, the market-expansion effect may induce the low-end firm to invest more in customer learning than the high-end firm even when the latter has a higher relative production efficiency, especially when horizontal match is relatively important.

Our model has its limitations. First, the binary distribution of match value simplifies analysis, as each product's reservation price is a linear function of CLI. A more general distribution exacerbates complexity but may not add significant new insights. Second, we have considered a duopoly. Although the optimal search rule developed by Weitzman (1979) applies to any finite number of options, the demand derivation becomes much more complex if there are more than two competing products. Third, because welfare analysis in a vertical setting is generally not tractable, we are unable to identify the effects of CLI on consumer surplus or social welfare. In the special case of symmetric investments, equilibrium qualities and prices remain the same as when neither firm invests, even though more customers will search. Consumer surplus thus increases. Last, aside from product quality, CLI may also affect the other marketing-mix variables. A direction for future research is to examine the impacts of CLI on horizontal differentiation. One possible set-up is that each product consists of two horizontal attributes, one observable and the other not. The observable attribute and the customers exist along a Hotelling line. When customers incur an evaluation cost to discover their valuation of the other attribute (i.e., match), one may investigate how the firms' CLIs affect locations of the observable attribute.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mksc.2015.0918.

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Appendix

Proofs of Propositions 2 through 6

Proof of Proposition 2. The firms' FOCs w.r.t. k_1 and k_2 are

$$h'(k_1^*) = \frac{2s}{9}\left[2+b+\frac{s(k_1^*-k_2^*)}{q_1^*-q_2^*}-\frac{c(q_1^*)-c(q_2^*)}{q_1^*-q_2^*}\right], \tag{24}$$

and

$$h'(k_2^*) = \frac{2s}{9}\left[1-b-\frac{s(k_1^*-k_2^*)}{q_1^*-q_2^*}+\frac{c(q_1^*)-c(q_2^*)}{q_1^*-q_2^*}\right]. \tag{25}$$

Their FOCs w.r.t. q_1 and q_2 are

$$2c'(q_1^*) = (2+b)-\frac{s(k_1^*-k_2^*)}{q_1^*-q_2^*}+\frac{c(q_1^*)-c(q_2^*)}{q_1^*-q_2^*}, \tag{26}$$

$$2c'(q_2^*) = -(1-b)-\frac{s(k_1^*-k_2^*)}{q_1^*-q_2^*}+\frac{c(q_1^*)-c(q_2^*)}{q_1^*-q_2^*}. \tag{27}$$

Any subgame perfect equilibrium (if it exists) must be jointly characterized by these four equations. Adding (24) and (25) leads to $h'(k_1^*)+h'(k_2^*)=2s/3$. Subtracting (27) from (26) leads to $c'(q_1^*)-c'(q_2^*)=\frac{3}{2}$. Combining (24) and (26) leads to $c'(q_1^*)=(2+b)-(9/(4s))h'(k_1^*)$. Combining (25) and (27) leads to $c'(q_2^*)=(-1+b)+(9/(4s))h'(k_2^*)$. Q.E.D.

Proof of Proposition 3. From (26) and (27), it is immediate that both firms' qualities decrease when $k_1^*>k_2^*$, increase when $k_1^*<k_2^*$, and remain unchanged when $k_1^*=k_2^*$. Q.E.D.

Proof of Proposition 4. From Proposition 2, we have $h'(k_1^*)=(4s/9)[(2+b)-c'(q_1^*)]$ and $h'(k_2^*)=(4s/9)[(1-b)+c'(q_2^*)]$. From these two equations, we have

$$h'(k_1^*)-h'(k_2^*)=\frac{4s}{9}[(1+2b)-c'(q_1^*)-c'(q_2^*)]. \tag{28}$$

From Proposition 2, we also have $c'(q_1^*)-c'(q_2^*)=\frac{3}{2}$. Substituting $c'(q_2^*)=c'(q_1^*)-\frac{3}{2}$ and $c'(q_1^*)=c'(q_2^*)+\frac{3}{2}$ into the above equation, we obtain $h'(k_1^*)-h'(k_2^*)=(4s/9)[\frac{5}{2}+2b-2c'(q_1^*)]$ and $h'(k_1^*)-h'(k_2^*)=(4s/9)[-\frac{1}{2}+2b-2c'(q_2^*)]$, respectively. The statements of the proposition then follow. Q.E.D.

Proof of Proposition 5. Suppose $\beta>2s^2/9(q_1-q_2)$. From the expressions of k_1^* and k_2^*, it is clear that $k_1^*\geq k_2^*$ when $(c_1-c_2)/(q_1-q_2)\leq(1+2b)/2$ and that $k_1^*<k_2^*$ otherwise. When neither firm invests to lower product evaluation costs, firm 1's equilibrium profits are obtained by setting $k_1=k_2=0$ in π_1: $\pi_1^N=(1/(9(q_1-q_2)))[(2+b)(q_1-q_2)-(c_1-c_2)]^2$. Similarly, $\pi_2^N=(1/(9(q_1-q_2)))[(1-b)(q_1-q_2)+(c_1-c_2)]^2$. It is easy to check that $\pi_1\leq\pi_1^N$ when $k_1\leq k_2$ and that $\pi_2\leq\pi_2^N$ when $k_1>k_2$. Q.E.D.

Proof of Proposition 6. When neither firm invests in customer learning, the price equilibrium is obtained by setting $k_1=k_2=0$ in the price equilibrium given in the text. The statements of the proposition then immediately follow. Q.E.D.

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