Information Personalization in a Two-Dimensional Product Differentiation Model

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Abstract: We use a game-theoretic model to examine how information personalization by firms interacts with different dimensions of product differentiation (namely, horizontal and vertical differentiation). We consider the possibility that consumers attach different importance to various types of product differentiation, and report the equilibrium in terms of the "quality–fit" ratio, which measures the relative strength of preference for quality compared to preference for product fit and is a function of the cost of quality and the cost of product misfit. We also consider how different market structures (whether firms are similar or differentiated on the horizontal dimension

Journal of Management Information Systems / Fall 2009, Vol. 26, No. 2, pp. 69–95.

0742–1222 / 2009 $9.50 + 0.00.
DOI 10.2753/MIS0742-1222260204

ex ante) lead to different equilibriums when firms adopt personalization. We show that personalization by one firm leads to higher profits for both firms if product quality and misfit costs are high and the firms offer similar products ex ante. On the other hand, if firms offer differentiated products, personalization is profitable only if the effectiveness of the personalization technology is high or if both product quality and misfit costs are low. We also highlight conditions under which investments in personalization and product quality can be complements or substitutes to each other. Finally, we show that a firm can respond to a competitor's personalization by either increasing (aggressive response) or decreasing (defensive response) investments in its own quality. Our results provide insights to managers on when to invest in personalization technologies and how to adjust their investments in product quality after the firm (or its competitor) adopts personalization.

Key words and phrases: game theory, horizontal and vertical differentiation, market structure, personalization, quality–fit ratio.

Personalization, also known as "one-to-one marketing" [20], refers to the practice of using information technology to treat customers on an individual basis by tailoring products, customer service, and other interactions uniquely for each customer. In other words, customers have unique tastes and preferences that may not always match the products available in the market. Firms are using technology to collect information about consumers' preferences and tailor products or customer service uniquely for each consumer. For example, the *Washington Post* (www.washingtonpost.com) allows its readers to create their own personal online newspaper that displays only the news topics that the readers are interested in, rather than displaying the newspaper's generic front page. Other examples of personalization where firms treat customers on an individual basis and offer different products to different consumers include Signature Supplements (vitamins; www.signaturesupplements.com) and Dell (computers; www.dell.com).

While recent research [11, 23] examines the personalization of physical products, there is little work on personalization of information. We address this shortcoming by modeling the economics of *information personalization* in this research. Firms personalize information in various ways: (1) firms tailor information goods such as news, music, and online content such that each customer receives only his or her preferred information (in this case, the core product, which is a digital good, is personalized), and (2) firms personalize information-related attributes of goods or services (in this case, information is auxiliary to the product; for example, Amazon.com sells books but also uses consumer information to create a personalized experience for shoppers by giving online recommendations). Thus, information personalization extends beyond information goods. Even firms that sell noncustomizable physical goods (e.g., books, apparel) or services (e.g., credit cards, financial services, online movie rentals) can create a personalized experience for their customers by tailoring the information-related attributes of the customer buying experience.

Information personalization is important because information age and ubiquity of the Internet have ushered an information overload. On the Internet, information overload manifests in the proliferation of numerous Web sites, and an increase in links and sublinks within each Web site. Firms offer personalized products to their customers to reduce information overload and increase user satisfaction [15]. For example, the online DVD rental firm Netflix has 90,000 DVD titles in over 200 genres. Consumers have a wide variety of preferences and it can be difficult and time-consuming for customers to search through and evaluate all of these options to locate a DVD they may enjoy. To resolve this issue, Netflix uses personalization technologies to make recommendations to consumers based on information about movies they or their friends watched or rated through Netflix's Web site.

There are numerous other examples of firms using information personalization. One such example is credit cards, which have many attributes, such as annual fees, membership points, and APR (annual percentage rate); and different customers may value these attributes differently. For example, some customers may value a low APR more than a low annual fee. Firms may differentiate horizontally by positioning themselves on select attributes (such as Capital One for rewards and Discover for cash back), or vertically (such as the Citi Simplicity card, which offers a higher quality level in terms of faster access to live representatives). Firms use information about consumer preferences to target the right credit card to the right consumer. Similarly, the *Wall Street Journal* (a business news Web site; www.wsj.com) and *Washington Post* (a general news Web site; www.washingtonpost.com) offer personalized content based on users' stated preferences.

Prior research on personalization [10, 23] focuses on horizontal differentiation where personalization reduces a user's misfit costs when a firm's product differs from the user's preferred product. In reality, firms simultaneously differ on other dimensions of product differentiation as well, such as vertical differentiation. For example, Amazon.com offers personalization and at the same time also offers higher quality levels (one-stop shopping, guaranteed delivery) than its competitors such as BestPrices.com. The impact of vertical differentiation on firms' decision to invest in personalization has not been studied, mainly because there is little prior research on multidimensional product differentiation models. Both personalization and product quality increase the utility that consumers derive from a product. Given that firms usually have finite resources at their disposal at any point in time, an interesting question that arises is whether firms should invest in personalization or in quality improvements, or both.

Prior analytical work on personalization [11, 23] assumes that personalization technology is always perfect and can help a firm in predicting consumers' preferences with complete accuracy. In reality, personalization technologies are not perfect and firms routinely invest in improving the accuracy of their recommendations. For example, in October 2006, Netflix announced a prize of $1 million to anyone who could improve the efficiency of its movie recommendation software by 10 percent (www.netflixprize.com).[1] We investigate firms' incentives to invest in new technologies that can improve the accuracy of prediction. In summary, prior research has characterized personalization as simplistic and static. In this paper, we enhance prior work by considering a firm's decision to invest in quality as well as in personalization. We examine a duopolistic market structure to study the role of competition in firms' decisions regarding personalization. Finally, we also let the personalization technology be imperfect and examine firms' decisions to improve prediction by investing in technology. More precisely, we consider the following research questions:

RQ1: Are personalization and quality substitutes or complements in equilibrium?

RQ2: How does personalization by one firm in a duopoly affect the competitor's investments in quality?

RQ3: Under what conditions does a firm find it profitable to personalize?

RQ4: How does the equilibrium change with improvements in firms' ability to personalize?

Our main results are as follows: we show that when firms are horizontally differentiated and the cost of product quality and misfit costs are high, personalization and quality are complements. However, when firms are locationally undifferentiated, personalization and quality are substitutes. Moreover, while our study reiterates results from prior literature that personalization by one firm can lead to lower profits for both firms when firms are horizontally differentiated, we show that this result holds only under certain conditions. By endogenizing firms' decision to invest in quality in our model, we are able to show that a firm can earn a higher payoff from personalization under horizontal differentiation if either the cost of quality and misfit costs are low or the effectiveness of the personalization technology is higher than a certain threshold. Further, if firms are locationally undifferentiated and the cost of quality and misfit are high, then personalization by one firm can increase profits for both firms. Our results also suggest that personalization by one firm can force a competitor to increase its product quality ("aggressive" response) if firms are locationally undifferentiated and the costs of quality and product misfit are high; otherwise, personalization by one firm can lead a competitor to reduce its investments in product quality ("defensive" response).

Finally, we contribute to the literature on two-dimensional product differentiation models by showing that in such models, given exogenous location choice and personalization adoption, firms choose to differentiate on either one (*MaxMin* differentiation) or both (*MaxMax*) or neither (*MinMin*) dimension, depending on the market structure and the costs of quality and product misfit.

Literature Review

Previous attempts to model personalization have analyzed product personalization, targeted promotions, personalized pricing, and highlighted conditions under which personalization is profitable [6, 7, 11]. Other studies have shown that personalization does not lead to higher profits for a firm even if competitors do not personalize

[5, 21, 26]. Aron et al. [1] model intelligent agent-based personalized pricing in a monopolistic setting. Murthy and Sarkar [17] summarize the current research in the management science area on personalization. Dewan et al. [10, 11] were the first to introduce the notion of offering a continuum of products rather than a single product. They examined firm profitability under both monopoly and duopoly structures after firms acquire customization capabilities. Syam and Kumar [23] extend this model to a more general setting by endogenizing the degree of customization in their model. These studies find that a firm can earn higher payoffs after customization if it restricts its scope of customization. Prior empirical research on personalization shows that consumers derive a higher utility by buying a personalized product [14, 24]; however, privacy concerns reduce consumers' desire to be profiled for personalization [2].

All prior models of personalization consider a one-dimensional product differentiation model. In reality, firms are differentiated both horizontally (based on consumer tastes, physical distance) and vertically (based on quality); so a two-dimensional model captures the reality better and provides additional insights that would be overlooked in a one-dimensional setting. Caplin and Nalebuff [4] were among the first to prove the existence and uniqueness of equilibrium in a two-dimensional setting. Neven and Thisse [19] solve a two-dimensional model for equilibrium price and product differentiation (both horizontal and vertical) and conclude that it is optimal for a firm to differentiate fully only on one dimension—that is, follow a *MaxMin* strategy. Telang et al. [25] also study horizontal and vertical differentiation of search engines, though they do not consider a two-dimensional product space. Weber [29] models the versioning policies of a monopolist when it can extend the product both horizontally and vertically. Degryse [9] uses a two-dimensional model to analyze the adoption of remote access in the banking industry.

Our paper makes a contribution to prior literature on personalization by analyzing personalization of information in a two-dimensional product differentiation model. Furthermore, we study personalization in the context of information, as opposed to personalization of physical products studied in prior literature (e.g., [23]). Personalization of information differs from personalization of physical goods in several ways. First, firms that personalize information (e.g., Netflix) usually offer personalization to all customers. On the other hand, firms such as Dell, which personalize physical goods, allow customers to choose between a nonpersonalized product and a personalized product. Second, the marginal cost of personalization for information goods is negligible. In the case of physical goods, the marginal cost of personalization is positive because the product needs to be physically changed for each customer. Information personalization, however, consists of tailoring information for each customer separately (e.g., a Web site may have thousands of dynamic pages of content or a direct marketer may have hundreds of different products). This requires investments in hardware and software, which are essentially fixed costs, and the marginal cost of personalization for each additional customer is usually negligible.[2] Third, firms that personalize information, such as Netflix (www.netflix.com), *Wall Street Journal* (www.wsj.com), eMusic (www.emusic.com), Movielink (www.movielink.com), and Starz Play (www.starz.com/channels/starzplay), charge a single price for all customers, irrespective of the level of personalization. This practice differs from physical goods where personalized products (e.g., Levi's jeans) are usually priced higher than non-personalized products.

Model

BEFORE WE INTRODUCE PERSONALIZATION, we present an outline of a general two-dimensional product differentiation model. We consider a market that has a broad product variety (horizontal differentiation) and various possible quality levels (vertical differentiation). To model such a product where consumers value both the *product fit* (choosing a product that closely matches their preferences) as well as *product quality* (higher quality is always preferable to low quality), we consider a two-dimensional model of consumer preferences—a horizontal component x representing product preference (e.g., [12]) and a vertical component θ representing willingness to pay per unit of quality (e.g., [18, 22]). Thus, the coordinates (x, θ) represent the position of any consumer in the X-Y plane. We make widely used assumptions regarding consumer utility in product differentiation models [11, 19]. Our assumptions are as follows:

Assumption 1: Consumer preferences are distributed uniformly over a square of unit area on the X-Y plane such that $x \in [0, 1]$ and $\theta \in [0, 1]$.

Assumption 2: Consumer's willingness to pay for quality is increasing in quality; that is, $g(\theta, q) = \theta \cdot q$, where θ is consumer type, which denotes willingness to pay for quality, and q is the quality level.

Assumption 3: Consumer's disutility due to product misfit, m, is increasing in the distance between the consumer's preference and the actual product offered by the firm; that is, $m(t, x, z) = t\,|x - z|$, where x and z are the locations of the consumer and firm, respectively, and t ($t > 0$) is the per unit cost of misfit (traditionally called misfit cost or transportation cost). The misfit cost t captures consumers' preference for product fit.

Assumption 4: Reservation price, R, is large enough such that in equilibrium the entire market is covered. Further, we assume that each consumer buys only one unit of the good.

Assumption 5: We assume a quadratic cost function, $c(q)$, for product quality such that $c(q) = k \cdot q^2$.

Consider a duopoly model where firms locate at z_1 and z_2 and offer products of quality q_1 and q_2 at price p_1 and p_2, respectively. Thus, (z_1, q_1) and (z_2, q_2) represent the position of firms 1 and 2, respectively, in the two-dimensional space. Without loss of generality, we assume that $q_1 \geq q_2$.

Consumer utility for a product (z_1, q_1) offered by firm 1 is given by $U_1 = R + \theta \cdot q_1 - t \cdot |x - z_1| - p_1$. Similarly, for firm 2, $U_2 = R + \theta \cdot q_2 - t \cdot |x - z_2| - p_2$. The set of consumers who are indifferent between buying a product from either firm is a line intersecting the X-Y plane. The equation for this line is given by solving $U_1 = U_2$. Mathematically,

$$\theta(x) = \frac{p_1 - p_2}{q_1 - q_2} - \frac{t\left(|x - z_2| - |x - z_1|\right)}{q_1 - q_2}. \tag{1}$$

Modeling Personalization

We use a modified version of the framework provided by Dewan et al. [11] to operationalize the impact of personalization technology from an economic standpoint. For a standard product offered at a price p, the consumer utility is given by $U = R + \theta \cdot q - p - t \cdot |x - z|$. By definition, personalization is the ability of a firm to offer a product that matches each user's preferences. Therefore, personalization can be represented as a firm acquiring the capability of locating at multiple points instead of a single point on the line; the utility that a consumer gets from a personalized product is $U = R + \theta \cdot q - p$. However, technological limitations prevent a firm from accurately predicting customer preferences at all times. Therefore, we introduce a parameter δ to represent the effectiveness of personalization. For a given personalization technology, δ represents how accurately the firm can predict consumer preferences and tailor the information content to match with the consumers' preferences. Therefore, we represent the utility function with personalization as $U = R + \theta \cdot q - p - t \cdot |x - z| \cdot (1 - \delta)$. Clearly, $0 < \delta < 1$ ($\delta = 0$ represents a nonpersonalized product and $\delta = 1$ represents an accurately personalized product as given in Dewan et al. [11]). The key point to note here is that although both personalization and quality lead to an increase in consumer utility, there is a conceptual difference between the two. In case of personalization, the increase in utility ($= t \cdot |x - z| \cdot \delta$) varies according to the consumer's location on the horizontal dimension. On the other hand, consumers' increase in utility due to quality ($= \theta \cdot q$) is independent of the consumers' location on the horizontal dimension.

Before presenting our analysis, we highlight two key features of a two-dimensional model.

Quality–Fit Ratio

In a two-dimensional model, consumers have a preference for product fit as well as for quality. We assume the total consumer utility is the sum of the consumer utility on each dimension. We introduce a term *quality–fit ratio* or *Q–F ratio* to denote which dimension is preferred more by the consumer. For example, a low Q–F ratio indicates that consumers have a strong preference for product fit (such as business news versus political news; high-risk investments versus low-risk investments). Put another way, their disutility from buying a product that does not fit their tastes is high. On the other hand, a high Q–F ratio indicates that quality levels are more important to consumers relative to the product attributes, or disutility from lack of product fit is small. For example, in the case of credit cards, consumers may care more about quality, as indicated by fraud protection services and level of customer service, than whether the card gives reward points or cash back. Mathematically, Q–F ratio $\gamma = (q_1 - q_2)/t$, where q_1 and q_2

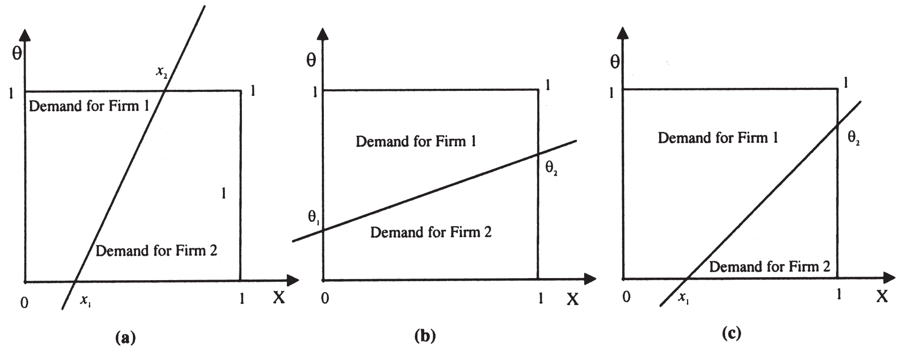


Figure 1. Possible Configurations for the Indifference Curve and Corresponding Demand

are the levels of quality offered by the firms and t is the transportation cost. A higher t indicates higher disutility from product fit and hence a low Q–F ratio.

The slope of the indifference line in Equation (1) depends on the (Q–F) ratio, $\gamma = (q_1 - q_2)/t$. Based on the position of the indifference line on the $X\text{-}Y^+ \in [(0,1),(0,1)]$ plane, the demand for firm 1 and firm 2 can be characterized in various ways, as shown in Figure 1. For example, if the indifference line intersects both $\theta = 0$ and $\theta = 1$ lines on the $X\text{-}Y^+$ plane, then each firm captures customers located close to it for all values of θ, as shown in Figure 1a. In this case, the consumer's preference for *product fit* dominates his or her preference for quality; this is known as *horizontal dominance* or H [19]. For example, *horizontal dominance* is a characteristic of markets (business news versus political news; high-risk versus low-risk investments) where products are differentiated and consumers experience a huge disutility due to misfit (high values of t).

However, if the indifference line intersects both the $x = 0$ and $x = 1$ lines on the $X\text{-}Y^+$ plane, firm 1 captures all customers who have a higher preference for quality and firm 2 captures all customers who have a lower preference for quality, as shown in Figure 1b. In this case, the consumer's preference for quality dominates his or her preference for fit; this is known as *vertical dominance* or V [19]. For example, *vertical dominance* is a characteristic of markets (such as online music services; eMusic) where products are relatively homogeneous (low values of t) and firms primarily differentiate on quality.[3]

Market Structure

In our model, firms' location on the horizontal dimension is exogenously determined before the start of the game.[4] Prior studies have mainly considered the case where firms are maximally differentiated on the Hotelling line [11, 13]. d'Aspremont et al. [8] show that firms find it optimal to locate at the opposite ends of the Hotelling line. However, competition between direct marketers can also be represented by firms occupying the same position in the horizontal dimension [3]. For example, Amazon.com and

Table 1. Different Scenarios in the Game

	Horizontal dominance (H)	Vertical dominance (V)
Locationally differentiated (D)	DHnP DHP DHPP	DVnP DVP DVPP
Locationally undifferentiated (U)	UHnP UHP UHPP	UVnP UVP UVPP

BestPrices.com both sell similar books and are largely undifferentiated on product type. However, Amazon.com offers a much higher quality in terms of better user interface, product reviews, and additional features such as search capability. We consider both market structures in our model: (1) when firms are located at the opposite ends of the Hotelling line (locationally differentiated, or D) and (2) when both firms are situated in the center of the market (locationally undifferentiated, or U). To summarize, we outline the various scenarios as shown in the 2×2 matrix in Table 1.

The first letter in each cell stands for whether the firms are locationally differentiated or undifferentiated (D or U); the second letter stands for whether the equilibrium is horizontal dominance or vertical dominance (H or V). The remaining letters stand for which firm personalizes. nP (no personalization) is the case when neither firm adopts personalization, P is the case when one firm adopts personalization, and PP is the case when both firms adopt personalization. Therefore, DHnP stands for the case where firms are locationally differentiated (D), the equilibrium is horizontal dominance (H), and neither of the firms personalizes (nP).

For each of the above scenarios (12 in all), the game proceeds in two stages as shown in Figure 2. In the first stage, both firms simultaneously choose their quality levels, and in the second stage, they simultaneously choose prices. Subsequent to this, consumers choose which firm's product to buy. This sequence of stages in firms' decision making is commonly used in industrial organization literature (e.g., [7]).

We use backward induction to solve the two-stage game. We first calculate the equilibrium price in the second stage by differentiating the profit function with respect to price and solving the first-order conditions. Next, we substitute the equilibrium values of price in the profit function and solve the first-order condition with respect to quality to calculate the optimal quality levels. Table 2 summarizes the notations used in the paper.

Locationally Differentiated Market Structure (D)

In this case, firms are located at the two ends such that $z_1 = 0$ and $z_2 = 1$. In this market, indifferent customers lie along the indifference line given by

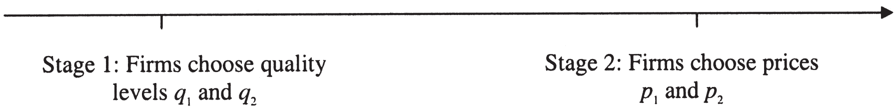


Figure 2. Stages of the Game

Table 2. Summary of Notations

Notation	Interpretation
t	Transportation cost; is an indicator of the extent of consumers' preference for product fit.
k	Unit cost of quality; the cost of a product of quality level q is given as $c(q) = kq^2$.
δ	Effectiveness of personalization; the higher the value of δ, the greater is the probability that a consumer receives a product that matches his or her tastes.
θ	Customers' willingness to pay for quality; consumers with a higher θ are willing to pay more for quality.
x	Location of the consumer on the horizontal dimension.
z	Location of the firm on the horizontal dimension.
q_i^{abc}, p_i^{abc}, π_i^{abc}	Equilibrium quality, price, and profits, respectively, of firm i (where $i = 1, 2$) in the scenario a, b, c, where $a = D$ or U; $b = H$ or V; and $c = nP$, P, or PP (refer to the scenario matrix from Table 1 for more details).

$$\theta(x) = \frac{p_1 - p_2 - t}{q_1 - q_2} + \frac{2 \cdot t \cdot x}{q_1 - q_2}. \tag{2}$$

Locationally Differentiated with Horizontal Dominance (DH)

No Firm Personalizes (DHnP)

Consider the indifference line $\theta(x)$ in Figure 1 intersecting $\theta(x) = 0$ and $\theta(x) = 1$ at x_1 and x_2, respectively. By calculation,

$$x_1 = \frac{p_2 - p_1 + t}{2 \cdot t};\ x_2 = \frac{p_2 - p_1 + t + q_1 - q_2}{2 \cdot t}.$$

The demand functions D_1 and D_2 for firm 1 and firm 2, respectively, are

$$D_1 = x_1 + \int_{x_1}^{x_2} (1 - \theta)\, dx;\ D_2 = 1 - x_2 + \int_{x_1}^{x_2} \theta \cdot dx.$$

Therefore, profits can be expressed as

$$\pi_1 = D_1 \cdot p_1 - kq_1^2;\ \pi_2 = D_2 \cdot p_2 - kq_2^2. \tag{3}$$

Solving the two-stage game for equilibrium quality and prices, we can summarize the results as follows: when firms are maximally differentiated horizontally and no firm personalizes, there exists a pure strategy Nash equilibrium such that the equilibrium prices and profits are given as follows:

$$p_1^{DHnP} = p_2^{DHnP} = t;\ q_1^{DHnP} = q_2^{DHnP} = \frac{1}{12k};\ \pi_1^{DHnP} = \pi_2^{DHnP} = \frac{t}{2} - \frac{1}{144k}.$$

To check whether the equilibrium is indeed horizontal dominance, it is sufficient to verify that $0 < x_1, x_2 < 1$. This result suggests that if firms are located at endpoints of a line, they offer the same quality level at the same price. Both firms earn the same profits. This is the case of *MaxMin* differentiation where firms choose to differentiate on only one dimension of product differentiation.

One Firm Personalizes (DHP)

We consider the case when one firm (say, firm 1 without loss of generality) adopts personalization. Solving the consumer utility functions $U_1 = U_2$, the indifference line is now given as

$$\theta(x) = \frac{p_1 - p_2 - t}{q_1 - q_2} + \frac{t \cdot (2-\delta) \cdot x}{q_1 - q_2}. \tag{4}$$

We solve the two-stage game for quality and price respectively using backward induction. In the second stage, we calculate the equilibrium prices by solving the first-order conditions of the firms' profit with respect to price. The equilibrium prices and profits (after substituting values of p_1 and p_2 in the firms' profit function) in the second stage are given as

$$\begin{gathered} p_1 = \frac{1}{6}(q_1 - q_2) + t\left(1 - \frac{\delta}{3}\right);\ p_2 = \frac{1}{6}(q_1 - q_2) + t \cdot \left(1 - \frac{2 \cdot \delta}{3}\right) \\ \pi_1 = \frac{\left(q_1 - q_2 + 2t(3-\delta)\right)^2}{36t(2-\delta)} - k \cdot q_1^2;\ \pi_2 = \frac{\left(q_1 - q_2 - 2t(3-2\delta)\right)^2}{36t(2-\delta)} - k \cdot q_2^2. \end{gathered} \tag{5}$$

In the first stage, we solve the first-order conditions of the profit function with respect to q_1 and q_2. The equilibrium quality and profits are as follows:

$$\begin{gathered} q_1^{DHP} = \frac{12k \cdot t(3-\delta) - 1}{\eta};\ q_2^{DHP} = \frac{12k \cdot t(3-2\delta) - 1}{\eta} \\ \pi_1^{DHP} = \frac{\left(12k \cdot t(3-\delta) - 1\right)^2 \cdot \phi}{\eta^2};\ \pi_2^{DHP} = \frac{\left(12k \cdot t(3-2\delta) - 1\right)^2 \cdot \phi}{\eta^2}, \end{gathered}$$

where $\eta = 12k(18k \cdot t(2-\delta) - 1)$ and $\phi = 36k \cdot t(2-\delta) - 1$.

The main results can be summarized in the following proposition:

Proposition 1: If firms are locationally differentiated and $k \cdot t > 1/(6(2\delta^2 - 7\delta + 6))$, *the firm that does not personalize earns lower profits—that is,* $\partial\pi_2^{LD,HD,P}/\partial\delta < 0$. *The firm that personalizes can earn higher or lower profits than the no-personalization case depending on the effectiveness of personalization.* $\partial\pi_1^{LD,HD,P}/\partial\delta > 0$ *if* δ *is higher than a certain threshold* δ^*. *Further, an increase in personalization effectiveness leads to an increase in the equilibrium quality level offered by the firm that personalizes—that is,* $\partial q_1^{LD,HD,P}/\partial\delta > 0$. *In other words, personalization and quality are complements. Also,* $\partial q_2^{LD,HD,P}/\partial\delta < 0$, *which suggests that personalization by one firm leads to a decrease in quality by the other firm.*

The condition $k \cdot t > 1/(6(2\delta^2 - 7\delta + 6))$ is necessary for the equilibrium to be horizontal dominance. Proof of Proposition 1 is shown in the Appendix.[5] The threshold value, δ^* $(= 1 - (1/36k \cdot t))$, depends on the cost of quality and misfit costs. This result suggests that under DHP, personalization can lead to lower profits for both firms (even when only one firm personalizes) than the no-personalization case if the effectiveness of the technology in predicting customers' preferences is low; but for higher values of personalization effectiveness, the firm that personalizes earns a higher profit. The intuition for this result is as follows: personalization reduces horizontal differentiation, reducing profits for both firms, when firms are ex ante horizontally differentiated [27, 28]. However, in a two-dimensional setup, quality differentiation between the firms increases with personalization ($\partial(q_1^{DHP} - q_2^{DHP})/\partial\delta > 0$), and at higher values of δ, the impact of quality differentiation dominates the price competition effect, yielding higher profits. Note that this result is unique to a two-dimensional model because one-dimensional models do not consider quality differentiation and overlook the interaction between personalization and product quality on equilibrium profits.

Thus, under DHP, personalization and quality are complementary strategies because firm 1 offers a higher-quality product after adopting personalization. Since personalization reduces the "effective" horizontal differentiation in DHP, firms differentiate more on the vertical dimension. Firm 1 invests more in quality and firm 2 responds to firm 1's personalization by lowering its own quality. We label this as a *defensive response* when a competitor reduces its investments in quality in response to the other firm's personalization. Notice that in the no-personalization case, both firms offer the same quality. However, personalization forces the firms to differentiate on quality.

Both Firms Personalize (DHPP)

Next, we repeat the above analysis for the case when both firms have the capability to personalize. We assume that both firms are symmetric in their capacity to personalize—that is, they offer a personalized product with the same effectiveness, δ. The results are as follows:

Proposition 1a: Under locational differentiation and horizontal dominance, when both firms personalize, equilibrium prices, quality, and profits are as follows:

$$p_1^{DHPP} = p_2^{DHPP} = t\left(1-\frac{\delta}{3}\right);\ q_1^{DHPP} = q_2^{DHPP} = \frac{1}{12k};$$
$$\pi_1^{DHPP} = \pi_2^{DHPP} = \frac{t(1-\delta)}{2} - \frac{1}{144k}.$$

Profits of both firms are decreasing in δ—that is, $\partial\pi_i^{DHPP}/\partial\delta < 0$ for $i = 1, 2$.

In this case, profits of both firms are decreasing in δ. The intuition is similar to that in scenario DHnP, where personalization leads to a reduction in the "effective" horizontal differentiation between firms and hence leads to price competition and lower profits. However, personalization is never profitable in this case because, if both firms personalize and are symmetric in their personalization capabilities, they offer the same quality level, and hence the quality differential that led to higher profits for firm 1 in DHP does not exist in this case.

Locationally Differentiated with Vertical Dominance (DV)

Vertical dominance (V) is a characteristic of markets with a high Q–F ratio—that is, both cost of quality and misfit costs are low. Without loss of generalization, let us assume that firm 1 is the high-quality firm—that is, $q_1 > q_2$.

No Firm Personalizes (DVnP)

When neither firm offers a personalized product, the equilibrium is as follows:

$$p_1^{DVnP} = \frac{4}{27k};\ p_2^{DVnP} = \frac{2}{27k}$$
$$q_1^{DVnP} = \frac{2}{9k};\ q_2^{DVnP} = 0 \qquad (6)$$
$$\pi_1^{DVnP} = \frac{4}{81k};\ \pi_2^{DVnP} = \frac{2}{81k}.$$

The condition for this equilibrium to be vertical dominance is $k \cdot t < 2/27$ (we test this by checking that $0 < \theta_1, \theta_2 < 1$ from Figure 1b). This result is a standard quality differentiation result where one firm offers a higher-quality product at a higher price and the other offers a lower-quality product at a lower price. Interestingly, even though firms are locationally differentiated (D), the equilibrium quality levels, prices, and profits are independent of t. The intuition is that each firm captures customers with all possible locational preferences (entire x-axis, as shown in Figure 1b). Therefore, firms' location on the x-axis does not play a strategic role in this case. This is supported by our results in scenario UVnP, where even though firms are locationally identical, the results in Equation (6) hold.

One Firm Personalizes (DVP)

Ex ante, since the firms are not symmetric in the no-personalization case, because one firm offers a higher-quality product while the other offers a lower-quality product (Equation (6)), we consider two separate cases: (1) when the high-quality firm personalizes and (2) when the low-quality firm personalizes. From the slope of the indifference line, we can infer that *vertical dominance* is the equilibrium for locationally differentiated firms if the Q–F ratio $\gamma \geq 2 - \delta$.

If firm 1 and firm 2 choose quality levels q_1 and q_2, respectively, in the first stage and the high-quality firm (firm 1) adopts personalization of effectiveness δ, the equilibrium profits and prices in the second stage are given as

$$p_1 = \frac{4\cdot(q_1 - q_2) + t\cdot\delta}{6};\ p_2 = \frac{2\cdot(q_1 - q_2) - t\cdot\delta}{6}$$
$$\pi_1 = \frac{(4\cdot q_1 - 4\cdot q_2 + t\cdot\delta)^2}{36(q_1 - q_2)} - k\cdot q_1^2;\ \pi_2 = \frac{(2\cdot q_1 - 2\cdot q_2 - t\cdot\delta)^2}{36(q_1 - q_2)} - k\cdot q_2^2. \quad (7a)$$

On the other hand, if the lower-quality firm (firm 2) adopts personalization with effectiveness δ, the equilibrium profits and prices in the second stage are given as

$$p_1 = \frac{4\cdot(q_1 - q_2) - t\cdot\delta}{6};\ p_2 = \frac{2\cdot(q_1 - q_2) + t\cdot\delta}{6}$$
$$\pi_1 = \frac{(4\cdot q_1 - 4\cdot q_2 - t\cdot\delta)^2}{36(q_1 - q_2)} - k\cdot q_1^2;\ \pi_2 = \frac{(2\cdot q_1 - 2\cdot q_2 + t\cdot\delta)^2}{36(q_1 - q_2)} - k\cdot q_2^2. \quad (7b)$$

From both Equations (7a) and (7b), we can show that $\partial\pi_2/\partial q_2 < 0$ always holds irrespective of the value of q_1, $c(q_2)$, and δ. Thus, firm 2 (which is the lower-quality firm) always offers the lowest quality level, even when it offers a personalized product. The equilibrium quality level of firm 1 can be obtained by solving the first-order condition, $\partial\pi_1/\partial q_1 = 0$. The closed-form expression for quality q_1 is shown in the Appendix and is not analytically tractable. However, we can solve for the impact of personalization on product quality and firm profits, as shown in the Appendix. The results are given in Lemma 1 and Proposition 2 (proofs are shown in the Appendix).

Lemma 1: The low-quality firm always offers the lowest possible quality level—that is, $q_2^{DVP} = 0$. The quality level offered by the high-quality firm decreases with δ—that is, $\partial q_1^{DVP}/\partial\delta < 0$. These results hold irrespective of whether the high-quality firm or the low-quality firm personalizes.

Thus, under DVP, if the high-quality firm personalizes, personalization and quality are substitutes; that is, the higher-quality firm can reduce its investments in quality after adopting personalization. If the low-quality firm personalizes, the high-quality firm responds by lowering its own quality level *(defensive response).* The intuition is that in case of V, the firms' location on the *x*-axis does not affect the results because both firms acquire all customers on the *x*-axis. However, personalization by one firm, in effect, creates horizontal differentiation between the firms, which allows firms to relax their quality differentiation. Also, under DVP, firms are differentiated on both horizontal and vertical dimensions. Thus, this is a case of *MaxMax* equilibrium.

> *Proposition 2: If firms are locationally differentiated and* $((q_1^{DVP} - q_2^{DVP})/t) > 2 - \delta$, *profits increase with* δ *for the firm that personalizes and decrease with* δ *for the other firm. In other words,* $\partial\pi_i/\partial\delta > 0$ $(\partial\pi_j/\partial\delta < 0)$, *where firm i (firm j) adopts (does not adopt) personalization.*

This proposition holds irrespective of whether the high-quality or low-quality firm personalizes, and suggests that under locational differentiation, if the Q–F ratio (which in turn depends on the cost of quality and misfit costs) is higher than a certain threshold, it is always profitable for a firm to personalize. Therefore, we can state that personalization is more likely to be profitable in markets where consumers' preference for quality dominates consumers' preference for product variety (which implies low cost of quality and misfit costs).

Both Firms Personalize (DVPP)

Repeating the above analysis for the case when both firms have the capability to personalize, we can show that the equilibrium profits and quality levels are the same as the no-personalization case mentioned in scenario DVnP. Firm profits and quality levels are independent of the personalization parameter, δ. The intuition is that since firms are symmetric in their personalization capabilities, and capture consumers over the entire x-axis (Figure 1b), the misfit cost on the horizontal dimension, t does not play any role in the final equilibrium.

Locationally Undifferentiated (U) Market Structure

In this case, firms are minimally differentiated horizontally and both firms locate at the center of the x-axis. Many firms that essentially sell undifferentiated goods such as books and CDs fall into this category, and these firms try to differentiate by offering a higher or lower quality level than their competitors. Online portals such as Yahoo! and MSN also offer products (mainly, information) that are largely horizontally undifferentiated. We incorporate this market structure in our two-dimensional model by considering both firms located at the center of the market—that is, $z_1 = z_2 = 1/2$.

Locational Undifferentiation with Horizontal Dominance (UH)

No Firm Personalizes (UHnP)

In the no-personalization case, since the firms are located at the same point on the x-axis, customers experience the same disutility if they buy from either firm. In other words, consider a customer located at a distance x from the center. His or her utility is given as $U_1 = R - \theta \cdot q_1 - p_1 - t \cdot x$ and $U_2 = R - \theta \cdot q_2 - p_2 - t \cdot x$. The indifference line is given as $\theta = p_1 - p_2/q_1 - q_2$. Since the indifference line is horizontal and independent of customer location x, no horizontal dominance equilibrium is possible.

One Firm Personalizes (UHP)

An interesting observation about locationally undifferentiated models is that personalization by one firm (firm 1) introduces a measure of horizontal differentiation—that is, it creates differential locational disutility. For example, consumers experience lower locational disutility if they buy a personalized product than if they buy a standard product. If firm 1 personalizes, the consumer utility now becomes $U_1 = R - \theta \cdot q_1 - p_1 - t \cdot x \cdot (1 - \delta)$ and $U_2 = R - \theta \cdot q_2 - p_2 - t \cdot x$, where x is the distance between the customer's ideal product and the center of the market ($z = 1/2$). The indifference line is

$$\theta(x) = \frac{p_1 - p_2}{q_1 - q_2} - \frac{t \cdot \delta \cdot x}{q_1 - q_2}. \tag{8}$$

This indifference line clearly depends on x and hence locational differentiation is created. Solving for price during the second stage and substituting the same in firm's profit functions, we obtain:

$$p_1 = \frac{1}{6}(q_1 - q_2 + 2 \cdot t \cdot \delta);\ p_2 = \frac{1}{6}(-q_1 + q_2 + t \cdot \delta)$$

and

$$\pi_1 = \frac{1}{18t\delta}(q_1 - q_2 + 2 \cdot t \cdot \delta)^2 - k \cdot q_1^2;\ \pi_2 = \frac{1}{18t\delta}(q_1 - q_2 - t \cdot \delta)^2 - k \cdot q_2^2. \tag{9}$$

Solving for the equilibrium in the first stage, we obtain the following results:

$$q_1^{UHP} = \frac{12k \cdot t \cdot \delta - 1}{12k(9k \cdot t \cdot \delta - 1)};\ q_2^{UHP} = \frac{6k \cdot t \cdot \delta - 1}{12k(9k \cdot t \cdot \delta - 1)}$$

$$\pi_1^{UHP} = \frac{(18k \cdot t \cdot \delta - 1)(12k \cdot t \cdot \delta - 1)^2}{144k(9k \cdot t \cdot \delta - 1)^2};\ \pi_2^{UHP} = \frac{(18k \cdot t \cdot \delta - 1)(6k \cdot t \cdot \delta - 1)^2}{144k(9k \cdot t \cdot \delta - 1)^2}.$$

Proposition 3: In a market where firms are locationally undifferentiated, and $k \cdot t > 2/9\delta$, profits of both firms increase when one firm adopts personalization. In other words, $\partial\pi_i/\partial\delta > 0$ for $i = 1, 2$. Also, the firm that personalizes offers a product of higher quality than the firm that does not personalize. Finally, the quality level of the personalizing firm decreases with δ—that is, $\partial q_1^{UHP}/\partial\delta < 0$—and that of the other firm increases with δ—that is, $\partial q_2^{UHP}/\partial\delta > 0$.

The condition $k \cdot t > 2/9\delta$ must be met for this equilibrium to be horizontal dominance. This result is interesting because it suggests that personalization adoption by one firm leads to an increase in profits for both firms in the market. The intuition is that the impact of personalization is to create horizontal differentiation in a market where firms are ex ante similar. Customers located farther away from the firms get a higher increase in utility from a personalized product than customers located closer to the firms. This enables firms to price higher and extract a higher surplus. This relaxation in price competition leads to increase in profits for both firms. The result is also interesting because it suggests that even though firms are locationally undifferentiated, horizontal dominance (H*)* can still be the equilibrium. In other words, personalization enables undifferentiated firms to earn nonzero profits. In such an equilibrium, the firm that personalizes captures customers located away from the center of the market and the firm that does not personalize captures customers located close to the center. We can show that as the cost of quality approaches zero, both firms will tend to choose identical quality levels (because $\partial\pi_i/\partial q_i > 0$ always holds in that case). Thus, under UH, firms are essentially minimally differentiated on both dimensions of product differentiation, thus leading to a *MinMin* equilibrium. Personalization and quality are substitutes in this case; that is, the firm that personalizes reduces its quality level as the effectiveness of personalization increases. Moreover, firm 2 responds to firm 1's personalization by increasing its quality level. We label this as *aggressive response* because the low-quality firm increases its investments in quality after the competitor personalizes.

Both Firms Personalize (UHPP)

In case both firms are symmetric in their capability to personalize, the indifference line is the same as in UHnP—that is, $\theta(x) = (p_1 - p_2)/(q_1 - q_2)$. Therefore, no equilibrium exists in this case.

Locationally Undifferentiated with Vertical Dominance (UV)

No Firm Personalizes (UVnP)

When firms are locationally undifferentiated and $k \cdot t < 4/9\delta$, the equilibrium profits and prices can be summarized as

$$p_1^{UVnP} = \frac{4}{27k};\ p_2^{UVnP} = \frac{2}{27k};\ q_1^{UVnP} = \frac{2}{9k};\ q_2^{UVnP} = 0;\ \pi_1^{UVnP} = \frac{4}{81k};\ \pi_2^{UVnP} = \frac{2}{81k}.$$

This result follows a standard vertical differentiation model [16]. The high-quality firm prices higher and earns more profits than the low-quality firm.

One Firm Personalizes (UVP)

The analysis of this scenario is similar to scenario DVP; therefore, we omit the details here. The result can be summarized in the following proposition.

> *Proposition 4: Under conditions of locational undifferentiation and vertical dominance (for* $((q_1^{UVP} - q_2^{UVP})/t) > (\delta/2)$*), profits increase with* δ *for the firm that personalizes and decrease in* δ *for the firm that does not personalize.*

Both Firms Personalize (UVPP)

If both firms have the capacity to personalize, the equilibrium is the same as in DVPP. Overall, the results in case of UV are generally similar to the DV. This confirms our earlier explanation that in vertical dominance (V) where both firms capture all customers on the *x*-axis, firms' location is not likely to play a significant role.

Summary

We summarize our results regarding the impact of personalization on firm profits and quality levels in Table 3.

Equilibrium Conditions

In this section, we compare the profit expressions from the last two sections to calculate the overall equilibrium; that is, which firm (if any) is likely to adopt personalization under different scenarios. For example, under the scenario DH (scenarios DHnP, DVP, and DVPP), the payoffs of firm 1 and firm 2 can be summarized in Table 4 depending on which firm adopts personalization.

Clearly, P (i.e., only one firm personalizes) is the Nash equilibrium if one firm earns a higher profit after personalizing (e.g., if $\pi_1^{DHP} > \pi_1^{DHnP}$). Since $\partial\pi_1^{DHP}/\partial\delta > 0$ for $\delta^* < \delta < 1$ (from Proposition 1), we can show there exists a value of δ such that $\pi_1^{DHP} > \pi_1^{DHnP}$. Solving

$$\frac{\left(12k\cdot t\left(3-\delta\right)-1\right)^2\cdot\phi}{\eta^2} > \frac{t}{2} - \frac{1}{144k},$$

we can show that this holds true for $\delta > \delta^{**}$, where

$$\delta^{**} = \frac{\left(504k\cdot t-19\right)-\sqrt{\left(72k\cdot t-1\right)\left(72k\cdot t+23\right)}}{288k\cdot t}.$$

Otherwise, nP is the Nash equilibrium. Further, we can show that firm 2 always earns more profits when only firm 1 personalizes than when both firms personalize—that is,

$$\frac{\left(12k\cdot t\left(3-2\delta\right)-1\right)^2\cdot\phi}{\eta^2} > t\frac{\left(1-\delta\right)}{2} - \frac{1}{144k}$$

always holds. Therefore, PP is never the Nash equilibrium. Similarly, we can derive the Nash equilibrium for each of the scenarios outlined in Table 1. In case of DV and UV, we do not use the closed-form solutions of the profit function, because it is analytically intractable. Instead, we derive the Nash equilibrium as follows: the firm that does not personalize in the P case earns lower profits than when neither firm personalizes (nP) or when both firms personalize (PP) ($\partial\pi_2^{DVP}/\partial\delta < 0$, implies that profits are highest

Table 3. Summary of Equilibrium Under Different Configurations

Market structure	Equilibrium	Who personalizes	Profits	Quality
D ($z_1 = 0$; $z_2 = 1$)	H	Firm 1	$\partial\pi_1/\partial\delta > 0$ for $\delta > \delta^*$; $\partial\pi_2/\partial\delta < 0$	$\partial q_1/\partial\delta > 0$; $\partial q_2/\partial\delta < 0$
	H	Both	$\partial\pi_1/\partial\delta < 0$; $\partial\pi_2/\partial\delta < 0$	$\partial q_1/\partial\delta > 0$; $\partial q_2/\partial\delta > 0$
D ($z_1 = 0$; $z_2 = 1$)	V	Firm 1	$\partial\pi_1/\partial\delta > 0$; $\partial\pi_2/\partial\delta < 0$	$\partial q_1/\partial\delta < 0$; $\partial q_2/\partial\delta = 0$
	V	Firm 2	$\partial\pi_1/\partial\delta < 0$; $\partial\pi_2/\partial\delta > 0$	$\partial q_1/\partial\delta < 0$; $\partial q_2/\partial\delta = 0$
	V	Both	Does not depend on δ	Does not depend on δ
U ($z_1 = z_2 = 1/2$)	H	Firm 1	$\partial\pi_1/\partial\delta > 0$; $\partial\pi_2/\partial\delta > 0$	$\partial q_1/\partial\delta < 0$; $\partial q_2/\partial\delta > 0$
	H	Both	Bertrand competition; zero profits	—
U ($z_1 = z_2 = 1/2$)	V	Firm 1	$\partial\pi_1/\partial\delta > 0$; $\partial\pi_2/\partial\delta < 0$	$\partial q_1/\partial\delta < 0$; $\partial q_2/\partial\delta = 0$
	V	Firm 2	$\partial\pi_1/\partial\delta < 0$; $\partial\pi_2/\partial\delta > 0$	$\partial q_1/\partial\delta < 0$; $\partial q_2/\partial\delta = 0$
	V	Both	Does not depend on δ	Does not depend on δ

Table 4. Deriving the Nash Equilibrium for DH

	Firm 1	
Firm 2	Does not personalize	Personalizes
Does not personalize	$\frac{t}{2}-\frac{1}{144k}, \frac{t}{2}-\frac{1}{144k}$	$\frac{\left(12k\cdot t(3-\delta)-1\right)^2\cdot\phi}{\eta^2}, \frac{\left(12k\cdot t(3-2\delta)-1\right)^2\cdot\phi}{\eta^2}$
Personalizes	$\frac{\left(12k\cdot t(3-2\delta)-1\right)^2\cdot\phi}{\eta^2}, \frac{\left(12k\cdot t(3-\delta)-1\right)^2\cdot\phi}{\eta^2}$	$t\frac{(1-\delta)}{2}-\frac{1}{144k}, t\frac{(1-\delta)}{2}-\frac{1}{144k}$

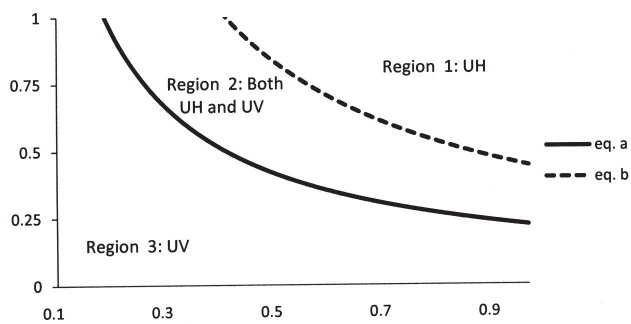
for $\delta = 0$, which is the no-personalization case). Therefore, the firm that does not personalize in the P case will always deviate from the Nash equilibrium by choosing to personalize. Hence, PP is the only Nash equilibrium in this case.

Both *H* and V equilibriums are possible for some values of $k \cdot t$ and δ. For example, the last two rows of Table 5 give the equilibrium in case of locationally undifferentiated firms (U). Horizontal dominance (H) is possible for $k \cdot t > 2/9\delta$ and vertical dominance (V) is possible for $k \cdot t < 4/9\delta$. Therefore, in the region $2/9\delta < k \cdot t < 4/9\delta$, both H and V are possible. This is shown in the graph in Figure 3(a). Equation a is $k \cdot t = 2/9\delta$ and equation b is $k \cdot t = 4/9\delta$. Similarly, the graph for locationally differentiated case (D) is shown in Figure 3(b). Equation c is $k \cdot t = 1/(6(2\delta^2 - 7\delta + 6))$ and equation d is $k \cdot t = 4/9\delta$.

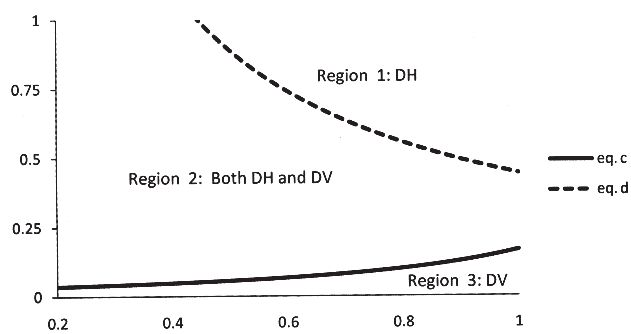
Table 5 highlights different conditions under which either one or both firms adopt personalization in equilibrium. For example, we find that both firms personalize in equilibrium if both cost of quality and misfit costs are low, irrespective of firms' location on the horizontal axis. On the other hand, if the quality and misfit costs are high, only one firm finds it profitable to personalize and both firms earn higher profits under U. Finally, under D, if cost of quality and misfit costs are high, neither firm finds it profitable to personalize if the effectiveness of personalization is below a certain threshold. However, when the effectiveness of personalization is higher than a certain threshold, the equilibrium changes such that one firm adopts personalization and the other does not. The intuition is as follows: when the marginal cost of quality is zero, both firms offer the highest possible quality level (because $\partial\pi_i/\partial q_i > 0$ for $i = 1,2$). Consequently, there is no vertical differentiation between firms, and profits go down after personalization. On the other hand, with a nonzero cost of quality, firm 1 offers a higher quality level than firm 2 and the quality differential increases with the personalization parameter δ. Therefore, for high enough values of δ, firm 1's profits increase with δ. The result that only one firm adopts personalization and earns higher profits points to the importance of first-mover advantage in these markets.

Table 5. Equilibrium Conditions When Both Firms Have the Capability to Personalize

Case	Condition	Which firm personalizes in equilibrium	Equilibrium
DH	$k \cdot t > \frac{1}{6\left(2\delta^2 - 7\delta + 6\right)}$	None	$\pi_1 = \pi_2 = \frac{t}{2} - \frac{1}{144k}$ for $\delta < \delta^{**}$
DH	$k \cdot t > \frac{1}{6\left(2\delta^2 - 7\delta + 6\right)}$	Firm 1	π_1^{DHP}, π_2^{DHP} (from scenario *DHP*) for $\delta > \delta^{**}$
DV	$k \cdot t < \frac{4}{9\delta}$	Both	$\pi_1 = \frac{4}{81k}$; $\pi_2 = \frac{2}{81k}$
UH	$k \cdot t > \frac{2}{9\delta}$	Firm 1	π_1^{UHP}, π_2^{UHP} (from scenario *UHP*)
UV	$k \cdot t < \frac{4}{9\delta}$	Both	$\pi_1 = \frac{4}{81k}$; $\pi_2 = \frac{2}{81k}$



(a) scenario U



(b) scenario D

Figure 3. Overall Equilibrium for Different Values of $k \cdot t$ and δ

Discussion and Conclusions

In this research, we extend prior work on personalization in several ways: (1) we consider a more general model where firms make decisions about both price and quality, (2) we model personalization in the context of products and services where information is the key element of personalization, (3) we use a general personalization parameter to account for the uncertainty in predicting customer preferences with accuracy, and (4) we model equilibrium conditions under different market structures. We find that such a two-dimensional setting is more insightful. For example, a one-dimensional model where firms can personalize to all customers [27, 28] predicts that personalization by a firm in a duopoly always leads to lower profits when firms locate at endpoints of a Hotelling line, even if the competitor does not personalize. For a two-dimensional model, we introduce the term *quality–fit (Q–F) ratio* to measure consumers' preference for either dimension of product differentiation (product fit versus product quality). In practice, the Q–F ratio would depend on two attributes of the market: the cost of quality, and product misfit costs, which customers experience if the product they buy does not match their preferences. We show that when firms are locationally differentiated (i.e., are located at opposite ends of the Hotelling line), prior results hold only when the quality and misfit costs are high and the effectiveness of the personalization technology is low. When these costs are low, personalization leads to higher profits for the firm that personalizes. A firm that personalizes can still earn higher profits than the no-personalization case, provided the effectiveness of the technology is high for markets where costs of quality and product misfit are high. For example, our model predicts that in case of competition between differentiated products, such as eMusic (www.emusic.com) versus Country Music Television (www.cmt.com) or the *Wall Street Journal* (www.wsj.com) versus the *Washington Post* (www.washingtonpost.com), personalization is adopted by a firm if the consumers' misfit costs and firms' costs of providing quality are low, or if the effectiveness of the technology is high.

We also consider the case when firms are locationally undifferentiated on the horizontal axis. We find that for high cost of quality and misfit costs, profits of both firms increase with personalization. For example, consider the case of Amazon.com and BestPrices.com in the online bookstores market where the products are largely undifferentiated and the preference for product fit is high (e.g., a customer who is interested in one type of book—say, computer books—cannot be easily persuaded to buy another type of book—say, architecture books). Our model predicts that in such a scenario, personalization by one firm (in this case, Amazon.com) will result in higher profits for both firms, which is also a result unique to two-dimensional models. Finally, we show that depending on the market structure, the Q–F ratio, and the personalization effectiveness parameter, either both or only one or none of the firms finds it optimal to personalize.

This research also contributes to the literature on two-dimensional differentiation models. We show that *MaxMin* equilibrium is not always dominant in such models [19]. Given that location choice is exogenously determined, we show that firms may choose to differentiate on both (*MaxMax*) or one (*MaxMin*) or no (*MinMin*) dimensions depending on the market structure, personalization adoption, and the Q–F ratio. The *MinMin* equilibrium is especially interesting because it suggests that under some conditions personalization allows firms to choose minimum differentiation on both dimensions. For example, personalization can enable firms such as mp3.com and eMusic.com, or DealCatcher.com and Deals2Buy.com, to differentiate and make positive profits even though both offer similar products.

In this research, we assume zero marginal cost of personalization—that is, the cost of personalization is independent of the personalization parameter δ. Assuming a nonzero cost of personalization will allow us to solve for an equilibrium personalization level. When a single firm adopts personalization, our results are not likely to change in this scenario. However, when we consider the scenario that both firms personalize, it is likely that firms choose different levels of personalization and we can have additional equilibriums depending on the market structure, the Q–F ratio, and the convexity of the personalization cost function. This could be an interesting extension to this research.

Some limitations of our work are as follows: although a two-dimensional model captures reality more closely than a pure horizontal differentiation only or pure vertical differentiation only, firms use a variety of strategic tools that can be too complex to capture in a single model. For example, firms use different types of pricing schemes such as multitier pricing (Netflix). Also, our model considers symmetric personalization capabilities for both firms. Future research can capture the case when firms are asymmetric in their personalization capabilities. We also assume that consumers derive a higher utility from personalization. In reality, consumers may respond negatively to personalization if the product recommendations do not match their preferences or if consumers are privacy conscious. Future research can also extend our model to these scenarios.

Notes

1. As of April 2009, no one was able to claim the prize.
2. We assume that some consumer information is available to the firm.
3. The indifference line can be somewhere in between, as shown in Figure 1c. We can verify that no Nash equilibrium lies in this region.
4. Location choice represents long-term consumer perceptions about a firm, and changing location requires significant investments by firms in product repositioning.
5. Proofs of remaining lemmas and propositions proceed similarly and are not shown here due to space limitations (unless specified).

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Appendix

Proof of Proposition 1

To verify how equilibrium quality level changes with δ, we derive the expression for $\partial q/\partial\delta$ as follows:

$$\frac{\partial\pi}{\partial q}=0\Rightarrow\left(\frac{\partial^2\pi}{\partial q^2}\right)\partial q+\left(\frac{\partial^2\pi}{\partial q\partial\delta}\right)\partial\delta=0\Rightarrow\frac{\partial q}{\partial\delta}=-\frac{\left(\frac{\partial^2\pi}{\partial q\partial\delta}\right)}{\left(\frac{\partial^2\pi}{\partial q^2}\right)}.$$

Using the profit expressions, we can show that

$$\frac{\partial^2\pi_1}{\partial q_1\partial\delta}=\frac{q_1-q_2+2t}{18t(2-\delta)^2}$$

and

$$\frac{\partial^2\pi_1}{\partial q_1^2}=\frac{1}{36t-118t\delta}-c''(q_1)$$

$$\frac{\partial q_1}{\partial\delta}=-\left(\frac{q_1-q_2+2t}{18t(2-\delta)^2}\Bigg/\left(\frac{1}{36t-18t\delta}-c''(q_1)\right)\right).$$

The numerator is positive. Denote the revenue of firm 1 by R_1 such that $R_1=D_1\cdot p_1$. Therefore, firm 1's profit is $\pi_1=R_1-c(q_1)$. The sign of the denominator depends on the $(\partial^2R_1/\partial q_1^2)-c''(q_1)$ term. Since $\partial R_1/\partial q_1-c'(q_1)=0$ at $q_1=q_1^*$ (equilibrium quality level) and also $\partial R_1/\partial q_1-c'(q_1)|_{q_1<q_1^*}>0$ and $\partial R_1/\partial q_1-c'(q_1)|_{q_1>q_1^*}<0$. Therefore, $(\partial^2R_1/\partial q_1^2)-c''(q_1)<0$. Hence, the denominator is negative and the overall expression for $\partial q_1/\partial\delta$ is positive. Therefore, the quality level of firm 1 increases with an increase in the effectiveness of its personalization. Similarly, we can show that the quality level of firm 2 decreases with an increase in the effectiveness of firm 1's personalization.

Profits for firm 1 under DHP are as follows:

$$\pi_1=\frac{\left(q_1-q_2-2t(3-\delta)\right)^2}{36(2-\delta)}-c(q_1),$$

where q_1 and q_2 are equilibrium quality levels. Taking the first-order condition with respect to δ, we can show that

$$\frac{\partial\pi_1}{\partial\delta}=\frac{\partial\pi_1}{\partial\delta}+\frac{\partial\pi_1}{\partial q_1}\cdot\frac{\partial q_1}{\partial\delta}.$$

Since $\partial\pi_1/\partial q_1$ is zero at equilibrium, the expression reduces to

$$\frac{\partial\pi_1}{\partial\delta}=\frac{\left(q_1-q_2+2t(3-\delta)\right)\left(q_1-q_2-2t(1-\delta)\right)}{36(2-\delta)^2}.$$

This is greater than zero only if the term $q_1 - q_2 > 2t(1 - \delta)$. At $\delta = 0$, the left-hand side is zero and the right-hand side is $+ve$. At $\delta = 1$, the left-hand side is $+ve$ and the right-hand side is zero. Since both the left-hand and right-hand sides are monotonic in δ, there exists at most one value of $\delta(=\delta^*)$ such that $\partial\pi_1/\partial\delta > 0$ for $\delta > \delta^*$.

Equilibrium in Scenario DVP

The equilibrium quality offered by the firm that personalizes is given by solving the first-order condition with respect to q_1. We can show that

$$q_1^{LD,VD,P}=\frac{16-\dfrac{32\left(2^{1/3}\right)}{\psi}+2^{2/3}\cdot\psi}{108k},$$

where

$$\psi=\left(2187(k\cdot t\cdot\delta)^2-128+27\sqrt{6561(k\cdot t\cdot\delta)^4-768(k\cdot t\cdot\delta)^2}\right).$$

Since this expression is analytically intractable and provides little additional insights into firm behavior, we outline the proof of Lemma 1 and Proposition 2 in the same manner as Proposition 1.

Proof of Lemma 1

To verify how equilibrium quality level changes with δ, we derive the expression for $\partial q/\partial\delta$ as follows:

$$\frac{\partial\pi}{\partial q}=0\Rightarrow\left(\frac{\partial^2\pi}{\partial q^2}\right)\partial q+\left(\frac{\partial^2\pi}{\partial q\partial\delta}\right)\partial\delta=0\Rightarrow\frac{\partial q}{\partial\delta}=-\frac{\left(\dfrac{\partial^2\pi}{\partial q\partial\delta}\right)}{\left(\dfrac{\partial^2\pi}{\partial q^2}\right)}.$$

Using the profit expressions, we can show that

$$\frac{\partial^2\pi_1}{\partial q_1\partial\delta}=-\frac{t^2\delta}{18(q_1-q_2)}$$

and

$$\frac{\partial^2 \pi_1}{\partial q_1^2} = \frac{(t \cdot \delta)^2}{18(q_1 - q_2)^3} - c''(q_1)$$

$$\frac{\partial q_1}{\partial \delta} = \left(\frac{t^2 \delta}{18(q_1 - q_2)^2} \Bigg/ \left(\frac{(t \cdot \delta)^2}{18(q_1 - q_2)^3} - c''(q_1) \right) \right).$$

The numerator is positive. Denote the revenue of firm 1 by R_1 such that $R_1 = D_1 \cdot p_1$. Therefore, firm 1's profit is $\pi_1 = R_1 - c(q_1)$. The sign of the denominator depends on the $(\partial^2 R_1/\partial q_1^2) - c''(q_1)$ term. Since $\partial R_1/\partial q_1 - c'(q_1) = 0$ at $q_1 = q_1^*$ (equilibrium quality level) and also $\partial R_1/\partial q_1 - c'(q_1)|_{q_1 < q_1^*} > 0$ and $\partial R_1/\partial q_1 - c'(q_1)|_{q_1 > q_1^*} < 0$, therefore, $(\partial^2 R_1/\partial q_1^2) - c''(q_1) < 0$. Hence, the denominator is negative and the overall expression for $\partial q_1/\partial \delta$ is negative. Therefore, the quality level of firm 1 decreases with an increase in the effectiveness of its personalization. Similarly, we can show that the quality level of firm 2 increases with an increase in the effectiveness of firm 1's personalization.

Proof of Proposition 2

Profits for firm 1 under DVP are as follows:

$$\pi_1 = \frac{(4q_1 - 4q_2 + t \cdot \delta)^2}{36(q_1 - q_2)} - c(q_1),$$

where q_1 and q_2 are equilibrium quality levels. Taking the first-order condition with respect to δ, we can show that

$$\frac{\partial \pi_1}{\partial \delta} = \frac{\partial \pi_1}{\partial \delta} + \frac{\partial \pi_1}{\partial q_1} \cdot \frac{\partial q_1}{\partial \delta}.$$

Since $\partial \pi_1/\partial q_1$ is zero at equilibrium, the expression reduces to

$$\frac{\partial \pi_1}{\partial \delta} = \frac{1}{18} t \left(4 + \frac{t \cdot \delta}{q_1 - q_2} \right).$$

This is always greater than zero.