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Product customization

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Abstract

The advent of the Internet has revolutionized the way companies advertise, develop and distribute products. Firms can now customize their advertising messages and products to the particular characteristics and needs of customers. Customers themselves can create their own products. We investigate investments by firms in product-customization capabilities within a duopoly model of horizontal product differentiation. We find that (i) if brand name effects are not too strong, one firm emerges as a leader in product customization—firms make asymmetric investments in product-customization technologies in order to reduce price competition, (ii) if brand name effects are strong, *both* firms make extensive investments in product customization, and (iii) the possibility of product customization can raise industry profits if brand names are weak, but not when they are strong.

JEL classification: D43; L13; O30

Keywords: Product customization; Brand name effects; Information acquisition; Horizontal differentiation

> Thanks to digital technology, the mass market of the 20th century is giving way to a market of one.
>
> Business Week. "Customizing for the masses." March 18, 2000.

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1. Introduction

The advent of the Internet has revolutionized the way companies advertise, develop and distribute products. Firms can now customize advertising messages and products to the particular characteristics and needs of customers. Customers themselves can create their own products. This is particularly prevalent with digital products, where the (marginal) costs of product customization are negligible. The Point Cast network delivers customized news based on a personal news profile.[2] Amazon.com customizes the page display according to each customer's past purchases and browses. Nike's website, www.nike.com, provides a ‘‘customize’’ option where consumers can create their most preferred athletic pair of shoes by choosing among many different options for base color, accent color, swoosh border, lace color, etc. So, too, many firms have customized advertising messages to consumers through the use of personalized banner ads and e-mails.[3]

Our paper investigates the strategic interactions between firms in a duopoly game of product customization. Firms first invest in information acquisition about customers and then customize their products as best as they can to match customer interests. In our core model, firms are ex ante identical—‘‘brand name’’ effects are absent—so that the two firms can potentially offer a consumer *exactly* the same customized product. In this model, a consumer's preferred product is captured by his spatial location on a circle. Firms can invest in information acquisition about this location with the goal of designing a product that matches the customer's interests. That is, a firm obtains a noisy signal about each consumer's true preferences and based on the signal it offers a personalized product. One can interpret the signal technology investment as an investment in a customer database. A greater database investment increases a firm's product-customization capability, raising the probability that a consumer will prefer that firm's product offering to its competitor's. Given the information-acquisition investments, firms set prices, and then consumers make purchase decisions.

The framework also maps into settings in which firms do not directly offer products, but rather invest in a technological infrastructure that allows consumers to create and customize their own products. A greater investment in product-customizing capabilities delivers a greater degree of flexibility for consumers creating their own products, so that consumers are more likely to be able to create products closer to their ideal products. With a slight modification of the spatial environment, the analysis also characterizes strategic outcomes in which firms choose the extent of their product lines, i.e., the variety of products offered. Therefore, we can use the terms ‘‘information acquisition’’, ‘‘investment in product-customization capabilities,’’ and ‘‘extent of product line’’ interchangeably.[4]

We show that, in equilibrium, one firm makes a minimal investment in product-customizing capabilities. The firm does this to mitigate the ensuing price competition: by not acquiring detailed information about customers, the firm credibly commits to

[2]Choi et al., 1997. The Economics of Electronic Commerce, p. 327.

[3]A recent paper that addresses the issue of personalized advertising is Gal-Or and Gal-Or (2005). The authors investigate the effect of customized advertising in television on the extent of price competition in the product market.

[4]There is a large management literature which is primarily concerned with how product customization can be implemented in practice. Toyota, for instance, offers many customization options to its Japanese customers, by allowing them to design their own cars using a computer-aided design (CAD) system in the dealer showroom (see Vickery et al., 1999). Åhlström and Westbrook (1999) offer many more product-customization examples.

ineffectively targeting consumers. This induces its rival to raise its price, allowing both firms to support higher equilibrium prices. If the cost of investment in customization (or of acquiring consumer-specific information) is not too great, equilibrium is characterized by *maximal differentiation* in product-customization capabilities. That is, one firm makes minimal investments, while the other develops a perfect capability in product customization. When such investments are costlier, one firm continues to make minimal investments, while the other makes a positive, but limited, investment in product-customization capabilities.[5]

These predicted asymmetric outcomes are consistent with what we see in practice. For example, Nike has created an on-line system with customizing capabilities; while Nike's major competitors, such as Adidas, offer fewer customizing options. So, too, Dell offers more customization options than many other PC manufacturers. The market for Database Management Systems (DBMS) is another in which the key players—IBM, Microsoft and Oracle—have made asymmetric investments in product customization: MS Access (a Microsoft product) is a one-size-fits-most application, whereas IBM is an expert in providing tailor-made solutions (Kretschmer, 2005).

The economy gives rise to multiple sources of inefficiency. First, consumers do not always buy their most-preferred product. This is because a firm that invests more in product customization charges a higher price. Therefore, in a model with fixed demand, some consumers purchase the cheaper product even when another product better matches their ideal product. Second, firms may not make the socially optimal investment in product customization. The problem of a social planner who chooses the product-customization investments given subsequent strategic pricing by firms reflects these trade-offs and others. Beyond pricing issues, the social planner must also weigh the benefits of spreading investments across convex technologies with the costs of having two imperfect technologies or noisy signals when only one good technology is required to target a consumer's preferred choice. We find that if investments in product customization are inexpensive, then to avoid distorting consumer choice, a social planner has both firms make significant investments in product customization. This redundancy in product-customization capabilities leads to symmetric pricing so that consumers purchase their most preferred products. As customization becomes more costly, the social planner finds such redundancy too expensive, and has one firm invest more than the other, trading off pricing-induced distortions in purchases against reduced investment costs. Finally, if investments in product customization are sufficiently costly, the social planner again chooses symmetric investments, which eliminates distortion in consumer choice, and spreads the investments out.

We then extend our core model by introducing a second, "brand name" dimension, which captures product characteristics that cannot be customized. "Brand names", trademarks (Nike's "Swoosh"), or patented features are tied to one firm and cannot be customized. Consumers differ in the degree to which they prefer one brand name to the other. Firms only know the distribution of brand name preferences so that prices are product-specific rather than consumer-specific. We prove that when consumers differ

[5]The idea that firms may do best to make heterogeneous investments in information acquisition has been advanced informally in the strategic marketing literature by Weiber and Kollmann (1998) who propose that it may be optimal for one firm to specialize in fast information acquisition, and others to specialize in high quality information acquisition.

enough on the "brand name", non-customizable dimension, then both firms make *symmetric*, strictly positive investments in product-customization technologies. Effectively, "brand name" serves to reduce the price elasticity of demand, softening the price competition induced by learning about the preferences of different consumers. This raises the attraction of investing in product-customization capabilities, as the firms compete away less of the surplus generated by identifying the exact products that different consumers prefer, or by developing a technology that permits consumers to tailor the product themselves.

The central result becomes: if "brand name" effects are strong enough, they "substitute" for asymmetric investments in product-customization capabilities, so that all firms make extensive investments. These increased investments raise consumer surplus, but offset some of the profits that firms earn from having more differentiated products. If, instead, brand name matters little, then one firm should emerge as a leader in product customization. The possibility of product customization raises total industry profits if such customization is sufficiently inexpensive, but not so inexpensive that brand name effects induce both firms to make extensive investments.

In real world contexts, this prediction suggests that if preferences vary sufficiently between the Nike brand name and the Adidas brand name among consumers, then "eventually" Adidas may mimic the level of Nike's investment in product customization. In contrast, brand name may matter less in computers or in DBMS, and certainly matters less in insurance, where consumers choose between generic insurance products and financial planners such as Northwestern Mutual, who invest significantly in individual relationships and tailor dynamically insurance and investments to individual investors.

1.1. Personalized products versus personalized prices

Consumer information can be used by firms to target consumers with personalized prices and to target them with personalized products. Our model emphasizes personalized products rather than personalized prices—prices are tied to the bundle that a consumer purchases. Such product-specific pricing results when firms do not know a consumer's "brand name" preference, and captures many real world scenarios—Nike charges a common price for all individuals who purchase the same shoe.

The distinction between personalized prices and personalized products is one that matters in terms of the economics—personalized products generate even fiercer price competition than personalized prices. Most transparently, in a Hotelling interval with two firms located at the endpoints, perfect price discrimination leads to strictly positive profits, whereas perfect product customization dissipates all profits. This suggests that because competition due to product customization is harsher than price-discrimination induced competition, firms may seek to differentiate themselves along "non-customizable" "brand name" dimensions.

Paradoxically, it is the fiercer competition associated with product customization that can raise total industry profits. If brand name effects are weak, firms so fear price competition due to product customization that in equilibrium, to soften price competition, only one firm invests significantly in information/customization. In this equilibrium, if information can be acquired sufficiently cheaply, industry profits are raised by the ability to customize products—because one firm provides a better product and extracts rents from doing so without engendering a price war, as the other firm refrains from engaging in product customization. This prediction contrasts with the typical prediction that the opportunity to price discriminate via personalized prices drives down industry profits (Thisse and Vives, 1988).[6] Indeed, our core model highlights that ex ante heterogeneity between firms is not even necessary to preserve firm rents, in contrast to standard spatial models. Instead, noisy information acquisition/imperfect investment in flexibility or limited product line, arises endogenously to serve a similar role.

Finally, we observe that because personalized products tie prices to the product rather than the individual, they can be reinterpreted as a framework in which consumers do the designing/selection, weakening the informational demands that are placed on firms (for example, firms do not need to know a consumer's preference for a ''Swoosh'' versus an ''N''). In many real world settings, this seems the appropriate informational assumption. In addition, while personalized prices have clear interpretations in travel settings, they are difficult to interpret in other economic settings, for example when considering the competition on product lines that we see between Nike and New Balance, on which this paper focuses.

1.2. Literature review

The literature mostly focuses on personalized pricing/price discrimination,[7] rather than personalized products/product customization. Here, we place our paper in the relevant product-customization literature. Most of this literature (a) takes as exogenous the information available about consumer tastes, (b) assumes that firms that customize, must do so perfectly,[8] and (c) melds personalized products with personalized prices.

In particular, Norman et al. (2001), endow firms with knowledge of the preferences/spatial location of consumers, and hence the ability to personalize prices, and a firm can tailor perfectly a product to a consumer's preferences at a cost that is increasing in distance between the firm' location and the consumer's. Dewan et al. (2000, 2003) consider a spatial structure in which the exogenously located firms can deliver products to sufficiently close customers for less than what the consumers would incur traveling to the firm's location. Firms choose the range of consumers to whom they offer to deliver with personalized prices, taking into account the pricing consequences. Travel economies are the greatest for more distant consumers, so that firms earn more profits from them, but serving more distant consumers also enhances inter-firm price competition. Dewan et al. show that in equilibrium, firms do not compete head-to-head on delivery, as the sets of consumers offered delivery are disjoint.

Our paper is most closely related to Liu and Serfes (2004) who consider a duopoly price discrimination setting with firms exogenously located at the opposing endpoints of the unit

[6] Ghose and Huang (2005) show that personalized prices need not lower firm profits if a second quality dimension is introduced and there are complementarities between quality and how close a consumer is to the firm. Firms know the distribution of preferences and choose a price-quality menu to offer to consumers. Due to the complementarities, firms gain more from the surplus created by offering close consumers higher quality at high prices than they lose from the increased price competition, reversing the standard prisoners' dilemma result.

[7] See, for example, Anderson and de Palma (1988), Chen (1997), Chen and Iyer (2002), Fudenberg and Tirole (2000), Liu and Serfes (2004), Shaffer and Zhang (2000), and Thisse and Vives (1988).

[8] In a dynamic price discrimination setting, Chen (2006) endogenizes consumer information acquisition decisions. More specifically, a firm decides—at the beginning of time—whether to acquire information, in order to perfectly target consumers with individual prices. Such a marketing innovation can be imitated by the rival firm with a time lag.

interval. Each firm chooses whether or not to acquire consumer-specific information of an exogenously fixed quality. The information allows the firms to partition consumers into different groups and charge each group a different price. The higher quality information translates into a finer partition. The exogenous spatial heterogeneity partially mitigates the intensity of price competition, so that firms make symmetric equilibrium investments in consumer information. By way of contrast, the central message of our paper is that when firms are ex ante symmetrically situated (due to their ability to offer customized products) and brand name effects are weak, then, when choosing the extent of product customization, firms have strong incentives to differentiate to reduce the subsequent price competition. As a result, firms make very different investments in product-customization capabilities.

In key contrast, we allow firms to endogenously acquire *any* amount of consumer information—and show that the distinction between endogenous and exogenous information acquisition is fundamental. Our paper also contributes to the literature by introducing non-customizable aspects of products, which are important in many real world contexts, and qualitatively alter equilibrium outcomes. "Branding" sources of heterogeneity in consumer preferences soften price competition, and raise the value of information that helps firms target better the desired products of consumers. As a result, firms acquire more information, and if brand preferences are sufficiently strong, a symmetric investment equilibrium results in which both firms make extensive investments, raising consumer surplus, and competing away some of the rents associated with brand name heterogeneity.

The paper is organized as follows. In the next section, we present the core model, which has only the customizable dimension. Section 3 presents the findings for the core model, and Section 4 contains the welfare analysis. In Section 5, we extend the core model by introducing a non-customizable, "brand name" dimension. We conclude in Section 6. All proofs are in the appendix.

2. The model

Two firms—1 and 2, indexed by i—offer competing products to a continuum of consumers (of measure one) who are uniformly distributed on a circle of unit circumference [e.g. Salop, 1979].[9] A consumer's location corresponds to his most preferred product. Specifically, a consumer with preferred product θ who purchases a product ℓ at a price p receives utility

$$V - t|\theta - \ell| - p,$$

where V is the utility derived from consuming his ideal product, θ, and $t>0$ measures the consumer's marginal disutility from consuming products further from θ. The utility of a consumer who does not purchase a product is normalized to zero. For simplicity, we assume that the marginal costs of production are equal, and we normalize them to zero.[10] Firms can invest in acquiring noisy signals about the location of each consumer's preferred product. At a cost of $c(a_i) = tka_i^2$, where $tk>0$, firm i acquires an information technology

[9]Due to the product-customization assumption, firms *do not* have fixed locations on the circle. In Section 5, we introduce a second "brand name" dimension. On that dimension firms *do* have fixed locations.

[10]Implicitly, we assume that the marginal cost is independent of the "degree" of customization. That is, a firm does *not* have a benchmark product, where the marginal cost rises with the distance between the customized and benchmark products. Altering this assumption merely means that setting marginal costs to zero ceases to be a normalization.

that provides it with signals of quality a_i about each consumer's most preferred product.[11] In particular, for each consumer θ, a signal quality a_i provides firm i with a signal $S^{\theta}_{a_i}$ of θ that is drawn from a uniform distribution on $[\theta - \frac{1}{2} + a_i, \theta + \frac{1}{2} - a_i]$, i.e., from a uniform distribution of length $2a_i$, centered around θ. We assume that there is no aggregate uncertainty, i.e., the idiosyncratic uncertainty at the individual signal level "washes out" in the aggregate.[12] The no aggregate uncertainty assumption implies that with probability 1, the distribution of "forecast errors", $S^{\theta}_{a_i} - \theta$, is uniformly distributed on $[-\frac{1}{2} + a_i, \frac{1}{2} - a_i]$. Following signal $S^{\theta}_{a_i}$, firm i's posterior over θ is uniformly distributed about $S^{\theta}_{a_i}$ on $[S^{\theta}_{a_i} - \frac{1}{2} + a_i, S^{\theta}_{a_i} + \frac{1}{2} - a_i]$: with the unit length of the circle, the quality choice $a_i = 0$ generates completely uninformative signals, while the signal quality choice of $a_i = \frac{1}{2}$ perfectly reveals each consumer's location.

One can alternatively view $c(a_i)$ as the fixed cost a firm has to incur to set-up a system (e.g. a web-page or a flexible manufacturing system) that allows for product customization. Hence, we use the terms "cost of information" and "cost of customization" interchangeably, and by modifying the spatial environment along the lines of Bernhardt and Massoud (2006), one can interpret the firms as choosing the extent of their product lines.[13] The fixed cost is an increasing function of the system's capabilities, which are measured by a_i. Let $\ell_i(s^{\theta}_i)$ denote the location on the unit circle of the product that firm i offers to the consumer whose signal realization is s^{θ}_i, and let $p_i(s^{\theta}_i)$ be the price.

Our modeling assumptions capture three key features of the Nike example highlighted in the introduction: (i) most of Nike's footwear customization is about color, a horizontal attribute, (ii) investment costs are largely the fixed costs of devising a flexible system, and (iii) the marginal costs of shoe production do not vary with the "particulars" of customization—shoes with black laces cost as much to produce as shoes with blue laces. More generally, Piller and Möslein (2002, p. 215) argue that most of the customization costs are the information costs that a firm must incur to elicit information about the specific needs of customers and transform these needs into a concrete product.

The timing of the game is as follows:

- *Stage* 1: *Investments in customization/information acquisition.* Firms choose simultaneously the quality of the information to acquire about consumer preferences, a_1 and a_2. Firms incur the (fixed) cost of customization $c(a_i)$ in this stage.
- *Stage* 2: *Product customization and pricing.* Firms see (privately) signal realizations for each consumer. Given the signals and first-stage signal qualities, they then choose the locations and prices of their products, $\ell_1(s^{\theta}_1; a_1, a_2)$ and $\ell_2(s^{\theta}_2; a_1, a_2)$, and $p_1(s^{\theta}_1; a_1, a_2)$ and $p_2(s^{\theta}_2; a_1, a_2)$.
- *Stage* 3: *Purchase decisions*. Each consumer purchases to maximize utility.

We search for a perfect Bayesian equilibrium (PBE).

[11]The normalization by multiplying by t eases presentation, and is without loss of generality.

[12]See Bergin and Bernhardt (1992) for a precise definition of the no aggregate uncertainty hypothesis. With a continuum of agents, signals cannot be independent, else technical concerns associated with measurability arise (Feldman and Gilles, 1985). The no aggregate uncertainty assumption exploits the fact that the economics depends on the realized distribution, and not on the particulars of the correlation structure that generates the realized distribution.

[13]In Bernhardt and Massoud, firms are endowed with distinct spatial dimensions, and individuals have firm-specific spatial locations that are independently distributed, so that the (closest) distance a consumer is from one firm's "product" is uncorrelated with the consumer's distance to the other firm's "product".

3. Analysis

We solve the game recursively.

Stage 3: Purchase decisions. Suppose the signal realizations for a consumer located at θ are s_1^θ and s_2^θ. This consumer will purchase firm 1's product if and only if,

$$V - t|\ell_1(s_1^\theta) - \theta| - p_1(s_1^\theta) \geqslant V - t|\ell_2(s_2^\theta) - \theta| - p_2(s_2^\theta)$$
$$\Longleftrightarrow |\ell_1(s_1^\theta) - \theta| \leqslant \frac{p_2(s_2^\theta) - p_1(s_1^\theta)}{t} + |\ell_2(s_2^\theta) - \theta|,$$

where we omit dependence on signal qualities of choices for ease of presentation.

Stage 2: Product customization and pricing. Firm 1 maximizes expected profits by choosing product locations to maximize the probability of the event that a consumer buys its product, i.e.,

$$\max_{\ell_1(s_1)} \Pr_1 = \Pr\left(|\ell_1(s_1^\theta) - \theta| \leqslant \frac{p_2(s_2^\theta) - p_1(s_1^\theta)}{t} + |\ell_2(s_2^\theta) - \theta| \right).$$

Because s_1 is drawn from a symmetric distribution around θ, firm 1 maximizes this probability by setting $\ell_1(s_1^\theta)$ equal to the median of its posterior distribution, i.e., $\ell_1(s_1^\theta) = s_1^\theta$. Similarly, firm 2 optimally sets $\ell_2(s_2^\theta) = s_2^\theta$. Hence, the probability that a consumer located at θ purchases the product that firm 1 designs for him is

$$\Pr_1 = \Pr\left(|s_1^\theta - \theta| \leqslant \frac{p_2(s_2^\theta) - p_1(s_1^\theta)}{t} + |s_2^\theta - \theta| \right).$$

Note that $(s_1^\theta - \theta) \sim \mathrm{U}[-\frac{1}{2} + a_1, \frac{1}{2} - a_1]$ and $(s_2^\theta - \theta) \sim \mathrm{U}[-\frac{1}{2} + a_2, \frac{1}{2} - a_2]$. A firm's pricing problem is therefore separable consumer by consumer. Because firms customize to the signal they receive, the signal disappears and therefore firm i will charge each consumer the same price, p_i, independently of the signal realization, s_i^θ. Further, without any loss of generality, we can consider a representative consumer $\theta = 0$; and because $|s_i^\theta - \theta| = |-s_i^\theta + \theta|$, we can focus on positive signal realizations, $s_1, s_2 \geqslant 0$. The next proposition summarizes the equilibrium in this stage.

Proposition 1 (*Existence and uniqueness of price equilibrium*). *In the unique equilibrium subgame following information quality choices $a_2 \geqslant a_1$, firm* 1, *which acquires less information about consumers, sets price $p_1^* = t(\frac{1}{4} - \frac{a_1}{3} - \frac{a_2}{6})$, while the better-informed firm* 2 *sets price $p_2^* = t(\frac{1}{4} - \frac{2a_1}{3} + \frac{a_2}{6})$.*[14]

Proof. See the appendix.

Interestingly, firm 1's equilibrium price *falls* with the investment in customization/information acquisition a_1 that it makes (*given* that $a_2 \geqslant a_1$). That is, even though acquiring better information allows firm 1 to provide (stochastically) a better product, in equilibrium the firms would engage in more bitter price competition with both firms lowering their prices.[15] It follows that a low information quality firm can set a higher price for its product only if it acquires less information about consumers. While this seems counterintuitive, it

[14] Clearly, a second equilibrium, symmetric to the one described in this proposition, exists when $a_1 \geqslant a_2$.

[15] This driving force also underlies a result that a pure strategy equilibrium does not exist when information acquisition and prices are chosen simultaneously.

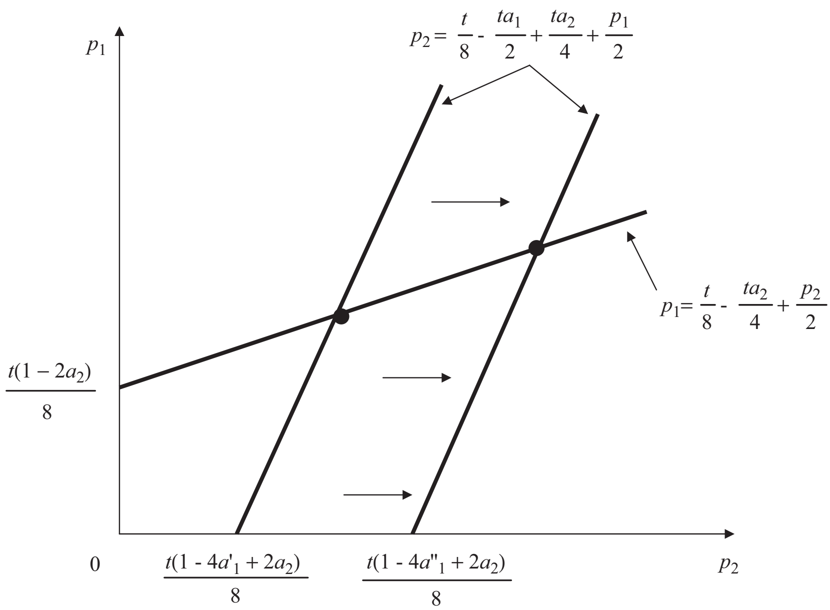

Fig. 1. Reaction functions when $a_2 \geqslant a_1$ and a_1 decreases.

reflects the value of commitment in this sequential game. By acquiring less information, the low quality firm commits to ineffectively targeting consumers. In response, the high-quality rival firm prices less aggressively, which allows the low-quality firm to sustain a higher price as well. Fig. 1 depicts these movements in the reaction functions space when $a_2 \geqslant a_1$ and firm 1 acquires less information (i.e., from a_1' down to a_1'').

Stage 1: Investments in customization/information acquisition. Substituting for equilibrium pricing as a function of the information acquisition decisions, we write firms' expected profits as a function of their information acquisition decisions:

$$\mathrm{E}\pi_1(a_1, a_2) = \frac{t(4a_1 + 2a_2 - 3)^2}{72(1 - 2a_1)} - tka_1^2 \tag{1}$$

and

$$\mathrm{E}\pi_2(a_1, a_2) = \frac{t(-8a_1 + 2a_2 + 3)^2}{72(1 - 2a_1)} - tka_2^2. \tag{2}$$

We now show that it is not an equilibrium for both firms to acquire the same quality of information about consumers, i.e., to choose $a_1 = a_2$, as one firm then wants to reduce its information acquisition in order to soften the subsequent price competition. To see this differentiate (1) and (2) with respect to a_1 and a_2, respectively, and evaluate the derivatives at $a_1 = a_2 = a$. This yields

$$\frac{\partial \mathrm{E}\pi_1(a,a)}{\partial a_1} = -\left(2tka + \frac{t}{12}\right) < 0 \quad \text{and} \quad \frac{\partial \mathrm{E}\pi_2(a,a)}{\partial a_2} = -2tka + \frac{t}{6}.$$

Firm 1 has an incentive to differentiate itself from its rival by acquiring less information. This has two positive effects on its profits. First, it mitigates the ensuing price competition and boosts profits, because as we have already alluded to, both firms can sustain higher prices. Second, the firm saves on the cost of information. The next proposition summarizes how equilibrium outcomes depend on the costs of information acquisition or product customization.

Proposition 2 (*Product-customization investments/information acquisition*). *Firms make asymmetric investments in product customization, with only one firm making significant investments. Investment, pricing, market share, and profits vary with product-customization costs according to*:

(i) *Low costs*, $k \leqslant \frac{2}{9}$.
Investment: $a_1^* = 0 < a_2^* = \frac{1}{2}$.
Pricing: $p_1^* = \frac{t}{6} < p_2^* = \frac{t}{3}$.
Market share: $\Pr_1 = \frac{1}{3} < \Pr_2 = \frac{2}{3}$.
Expected profits: $\mathrm{E}\pi_1 = \frac{t}{18} < \frac{t}{8} < \mathrm{E}\pi_2 = \frac{2t}{9} - \frac{kt}{4}$.

(ii) *High costs*, $k > \frac{2}{9}$.
Investment: $a_1^* = 0 < a_2^* = \frac{3}{2(18k-1)} < \frac{1}{2}$.
Pricing: $p_1^* = \frac{t(9k-1)}{2(18k-1)} < p_2^* = \frac{t9k}{2(18k-1)}$ *and* $\frac{\mathrm{d}p_1^*}{\mathrm{d}k} > 0 > \frac{\mathrm{d}p_2^*}{\mathrm{d}k}$.
Market share: $\Pr_1 = \frac{9k-1}{18k-1} < \frac{1}{2} < \Pr_2 = \frac{9k}{18k-1}$.
Expected profits: $\mathrm{E}\pi_1 = \frac{t(9k-1)^2}{2(18k-1)^2} < \frac{t}{8} < \mathrm{E}\pi_2 = \frac{9tk}{4(18k-1)}$.

Proof. See the appendix.

Proposition 2 shows that when information about consumers is inexpensive, $k \leqslant \frac{2}{9}$, firms *maximally differentiate* with respect to the quality of information. If information is costlier to acquire, then one firm acquires imperfect information, while the other continues to acquire minimal information. The firm that customizes charges a higher price.[16] Fig. 2 depicts the equilibrium levels of information acquisition. The properties of the product-customization game resemble the general features of a *hawk-chicken* game.[17]

It is useful to contrast equilibrium outcomes with those that obtain when firms have minimal information about consumers so that $a_1 = a_2 = 0$. Then, equilibrium prices are $p_1^* = p_2^* = \frac{t}{4}$ and expected firm profits are $\mathrm{E}\pi_1 = \mathrm{E}\pi_2 = \frac{t}{8}$. Thus, the availability of consumer information makes the firm that acquires information better off at the expense of its rival. Information acquisition about consumers raises joint firm profits if and only if the information can be acquired sufficiently cheaply, $k < \frac{1}{9}$ (see Fig. 3). Strategic interactions are more subtle when information is costlier to acquire, i.e., when $k > \frac{2}{9}$. Then firm 2 acquires increasingly noisy information about consumer preferences. This leads firm 2 to reduce its price. There are opposing impacts on firm 1—firm 2's price is lower, which, ceteris paribus, induces firm 1 to reduce its price; but firm 2's product tends to be less good,

[16]Empirically, firms that offer greater customization charge higher prices. For example, Kotha (1996) documents how NIBC, a Japanese bicycle company, implemented its mass customization strategy, pricing custom-made models 20–30% higher than similar non-customized bicycles.

[17]In addition to the pure strategy equilibrium characterized in Proposition 2, there is a symmetric mixed strategy equilibrium in which the two firms mix over extreme information acquisition choices, and nothing in between (i.e., 0 and $\frac{1}{2}$ when the customization cost parameter, k, is not too large). Details are available upon request.

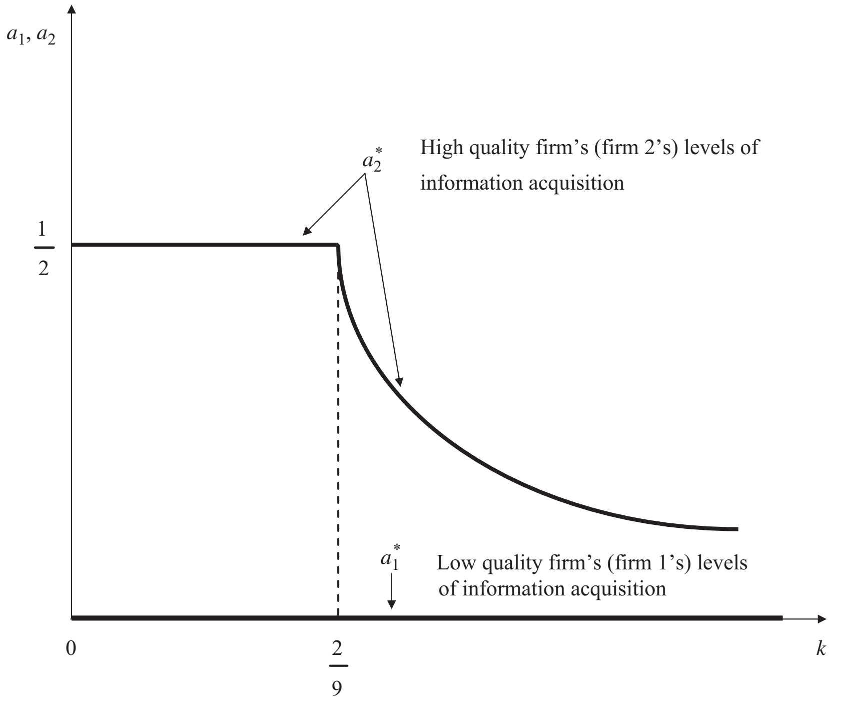

Fig. 2. Equilibrium levels of information acquisition.

which, ceteris paribus, induces firm 1 to raise its price. Proposition 2 details that this second effect dominates: the low quality firm 1's price, market share and profit all rise as information becomes costlier for firm 2 to acquire and firm 2's price, market share and profits fall (see Fig. 4).

Our asymmetric equilibrium prediction should be interpreted broadly. It is best interpreted as firms trying to keep a "distance" from each other in terms of product-customization capabilities, rather than one firm necessarily not customizing at all. For example, firms may already have some information about customers (that they cannot credibly commit not to use) and then the zero investment indicates that the firm chooses not to acquire any extra information (hence, we describe $a_1^* = 0$ as "minimal information", rather than zero). Indeed, our analysis extends almost immediately when firms have initial endowments of information—one firm acquires incremental information, while the other does not.

Equilibrium investments resemble the maximal product quality differentiation found in models of vertical differentiation (e.g., Shaked and Sutton, 1982), in which one firm chooses a product of zero quality (when the market is covered), keeping the quality of its product to a minimum level to soften the price competition. It is obvious that a symmetric quality choice (in pure strategies) cannot be an equilibrium in the Shaked and Sutton model, as all profits would be competed away. However, in our model, noisy, but imperfect, investments in product customization lead to positive firm profits. Therefore, it is not a priori obvious why symmetric, but *imperfect*, investments in product customization are not an equilibrium. Indeed introducing a second "brand name" dimension as we later do reverses this prediction.

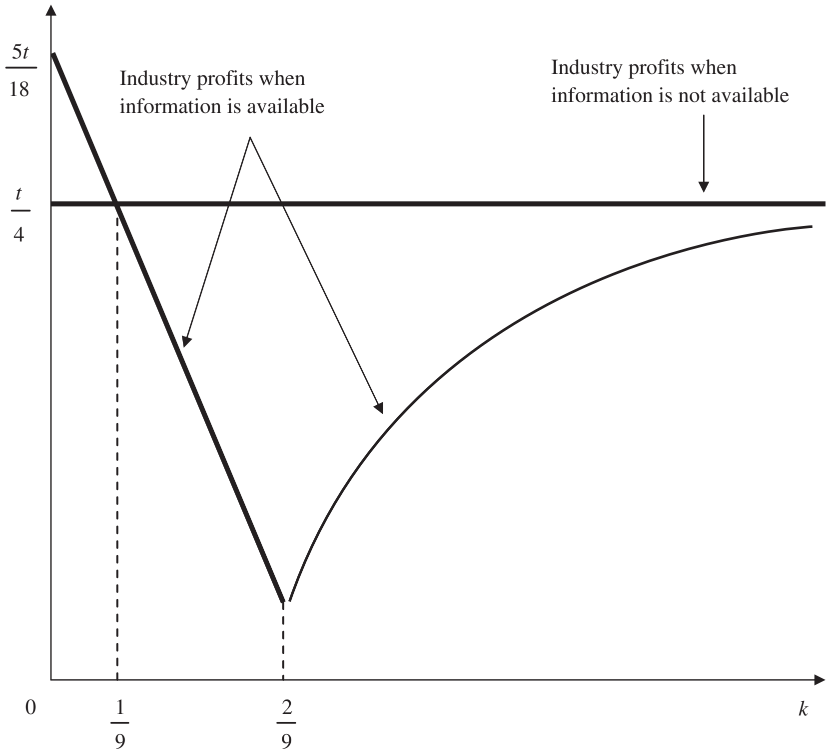

Fig. 3. Industry profits.

Because there are two asymmetric equilibria, a natural question that arises is: which firm opts for being the chicken? Contemplating additional heterogeneity suggests answers. If one firm starts out with an informational or cost advantage, then joint firm profits are the highest when the firm with the initial advantage is the one that invests, so that a Pareto criterion or introducing up-front transfers between firms would select this outcome. This outcome also qualitatively emerges if we allow for private information. We can extend our core model by allowing the information cost parameter k to be private information. One can show that it is the low cost firm that invests in product-customization capabilities. For example, if k is either low, $\underline{k}$, with probability p or high, $\bar{k}$, with probability $1-p$, then for reasonable parameter ranges, there is a symmetric PBE in which firms invest in product-customization capabilities if and only if their information costs are low. In particular, if $\underline{k}=0$, and $\bar{k}\geqslant\frac{7-11p}{18}$, then, for, $p\in[\frac{3}{5},\frac{7}{11}]$: $a(\underline{k})=\frac{1}{2}$ and $a(\bar{k})=0$. In this private information setting, firms can only imperfectly coordinate asymmetric investments. However, the qualitative feature that firms seek to differentiate product-customization investments maximally remains.

4. Welfare analysis

Because prices are transfers between consumer and producer, social surplus—total consumer plus producer surplus—just equals V minus both information costs and the

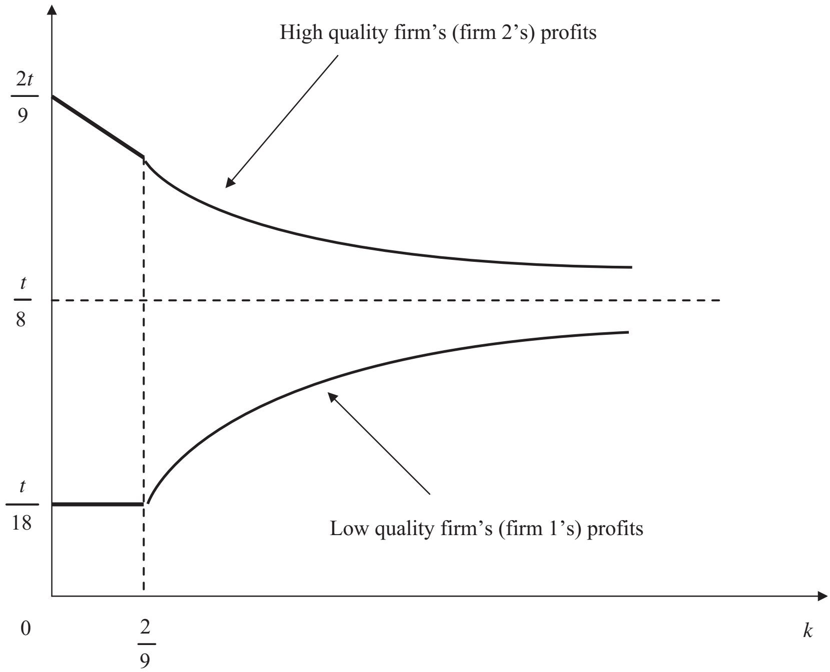

Fig. 4. Firms' profits.

expected disutility from purchasing a mis-targeted product. Consumer surplus equals social surplus minus total firm profits.

Low information cost: $k \leqslant \frac{2}{9}$. Since firm 2 perfectly learns a consumer θ's preferred product, θ's payoff if he purchases from firm 2 is $V - t0 - \frac{t}{3}$, while if he purchases from firm 1 his expected payoff is $V - ts_1 - \frac{t}{6}$. He chooses firm 1's product if and only if $s_1 \leqslant \frac{1}{6}$. It follows easily that the expected disutility due to a mis-targeted product is $\frac{t}{36}$. Therefore, social surplus is,

$$V - \frac{t}{36} - \frac{kt}{4},$$

implying a consumer surplus of

$$V - \frac{t}{36} - \frac{kt}{4} - \left[\frac{t}{18} + \frac{2t}{9} - \frac{kt}{4}\right] = V - \frac{11t}{36}. \tag{3}$$

High information cost: $k > \frac{2}{9}$. The representative consumer purchases firm 1's product if and only if $s_1 \leqslant s_2 + \frac{p_2^* - p_1^*}{t}$. His expected disutility due to consuming a less-preferred product is (details about the derivation are omitted)

$$\text{expected disutility} = \frac{t(648k^2 - 126k - 1)}{12(18k - 1)^2}. \tag{4}$$

Thus, expected social surplus is

$$V - \frac{t(648k^2 - 99k - 1)}{12(18k - 1)^2},$$

implying a consumer surplus of

$$V - \frac{t(1620k^2 - 234k + 5)}{12(18k - 1)^2}. \tag{5}$$

It is easily verified that lower information acquisition costs, i.e., lower k, raise both social and consumer welfare: consumers are made better off if firms can use information about them.

4.1. Social optimum

There are two sources of inefficiency in the economy. First, consumers may not buy the product they most prefer because while one product may be closer to a consumer's preferred product, prices also affect a consumer's decision. Second, firms may not acquire the "right" amount of information. We now consider how a social planner would choose investments in information when firms strategically choose prices given the information that the social planner acquired. To maximize social surplus, the social planner chooses information qualities a_1 and a_2 to minimize the sum of the expected disutility from consuming mis-targeted products plus the information costs, anticipating how firms will compete in prices. To highlight how the distortions due to competitive pricing affect the social planner's choice of information, we first consider the social planner's choices when prices are exogenously equated, so that consumers' decisions are not influenced by prices, ensuring that the most preferred product is purchased. Then, (omitting the details of the derivation) the social planner seeks to minimize the sum of expected consumer disutility plus information costs,

$$C = \frac{t(1 - 3a_1 - a_2 - 2a_2^2 + 6a_1a_2 + 6ka_1^2 - 12ka_1^3 + 6ka_2^2 - 12ka_1a_2^2)}{6(1 - 2a_1)}. \tag{6}$$

Lemma 3 (*Social optimum, prices exogenously equated*). *Suppose prices are exogenously equated, $p_1 = p_2$. Then the social planner makes symmetric investments in information acquisition about consumers if information costs are high, but asymmetric investments if information costs are low*:

1. *For $k \leqslant \frac{1}{2}$, $a_1^{so} = 0$ and $a_2^{so} = \frac{1}{2}$ (asymmetric corner solution).*
2. *For $k \in (\frac{1}{2}, \frac{5}{6})$, $a_1^{so} = \frac{12k-5-\sqrt{24k-11}}{24k} > 0$ and $a_2^{so} = \frac{-8k+5+\sqrt{24k-11}}{4k(1+\sqrt{24k-11})} < \frac{1}{2}$, where $a_2^{so} > a_1^{so}$ (asymmetric interior solution).*
3. *For $k \geqslant \frac{5}{6}$, $a_1^{so} = a_2^{so} = \frac{1}{12k}$ (symmetric interior solution).*

Proof. See appendix.

When prices are endogenously determined by competitive forces given the social planner's information choices, the social planner's objective is to minimize

$$C = \frac{t(3 + 2a_1^2 + 14a_1a_2 + 18ka_1^2 + 18ka_2^2 - 3a_2 - 4a_2^2 - 9a_1 - 36ka_1^3 - 36ka_1a_2^2)}{18(1 - 2a_1)}. \tag{7}$$

The next proposition summarizes the social planner's quality choices.

Proposition 4 (*Social optimum: Endogenous pricing*). *Suppose the social planner chooses information investments by firms and then firms choose prices to maximize profits. Then the social planner chooses symmetric investments whenever product-customization costs are low or high, but chooses asymmetric investments when product-customization costs are intermediate*:

1. *For* $k \leqslant \frac{1}{18}, a_1^{\mathrm{so}} = a_2^{\mathrm{so}} = \frac{1}{2}$ (*symmetric corner solution*).
2. *For* $k \in (\frac{1}{18}, \frac{7}{18}), a_1^{\mathrm{so}} = \frac{1}{36k} < \frac{1}{2}$ *and* $a_2^{\mathrm{so}} = \frac{1}{2}$ (*asymmetric corner solution*).
3. *For* $k \in [\frac{7}{18}, \frac{11}{18}], a_1^{\mathrm{so}} = \frac{-5+18k-\sqrt{-13+36k}}{36k} < \frac{1}{2}$ *and* $a_2^{\mathrm{so}} = \frac{-72k+35+7\sqrt{-13+36k}}{36k(1+\sqrt{-13+36k})} < \frac{1}{2}$, where $a_2^{\mathrm{so}} \geqslant a_1^{\mathrm{so}}$ (*asymmetric interior solution*).
4. *For* $k > \frac{11}{18}, a_1^{\mathrm{so}} = a_2^{\mathrm{so}} = \frac{1}{12k} < \frac{1}{2}$ (*symmetric interior*).

The proof is similar to that of Lemma 3 and is omitted. Figs. 5 and 6 depict the socially optimal levels of information that we derive in Lemma 3 and Proposition 4.

Contrasting Lemma 3 with Proposition 4 yields several important insights. If information is cheap to acquire, $k \leqslant \frac{1}{18}$, then when pricing is endogenous, not only is it optimal for the social planner to have both firms acquire information to avoid price differences that distort consumer purchases, but this information is also perfect. Were prices exogenously equated, consumer purchases would not be distorted by information acquisition, and Lemma 3 details that in this instance, the social planner would only have one firm acquire perfect information. There is no need to provide choice for consumers. As information becomes more expensive to acquire, the social planner finds information redundancy too expensive, and starts reducing information acquisition by one firm, trading off pricing-induced distortions in purchases against reduced information acquisition costs. Finally, if information costs are high enough, $k \geqslant \frac{11}{18}$, the social planner again chooses symmetric information investments, which eliminates distortion in consumer choice, and spreads the investments out over the two convex technologies.

Note that even when prices are exogenously equated, for $k \geqslant \frac{5}{6}$, the optimal product-customization decisions are symmetric. When information costs are this high, there is again redundancy in product-customization capabilities when both firms acquire noisy signals, but because the signals are noisy, offering noisy *choice* to consumers is welfare enhancing. It is also worthwhile to contrast the socially optimal product-customization choices with their competitive counterparts. Competitive firms purposely distort information choices to support higher prices, but this gives rise to socially inefficient product purchases. When information costs are small, only one competitive firm acquires information, but it is optimal for both firms to acquire perfect information to mitigate pricing-induced purchase distortions. More generally, the competitive outcome always has one firm acquire too much or too little information relative to the social optimum, and the other firm too little. The firms do so *precisely* to mitigate price competition, but the induced heterogeneity in prices distorts purchases.

It is more plausible that a regulator can control information acquisition/product customization, but not pricing. Therefore, it is more interesting to compare the Nash equilibrium with Proposition 4 where pricing is endogenous (see Fig. 7, where we combine Figs. 2 with 6).

The next corollary summarizes this comparison.

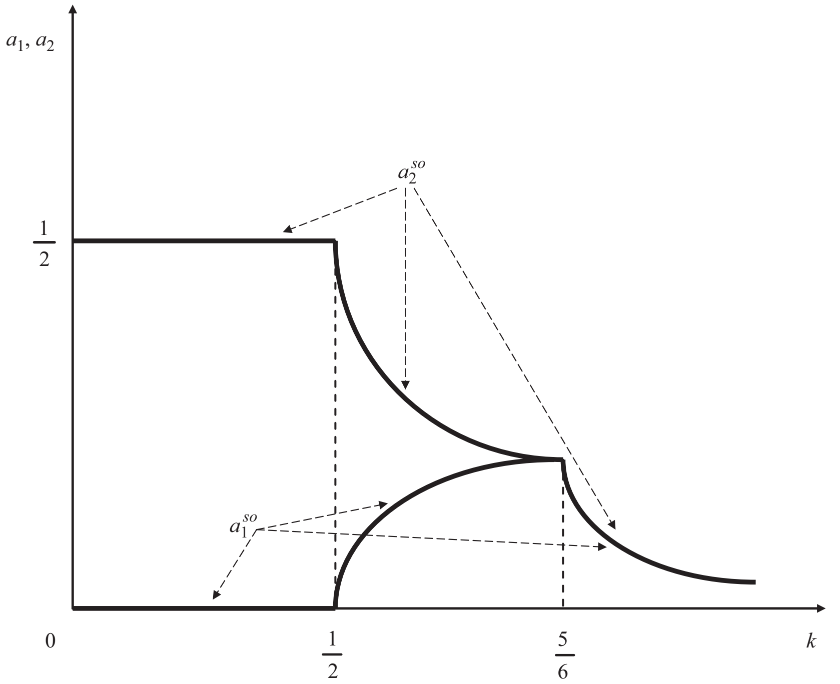

Fig. 5. Lemma 3 (exogenous pricing).

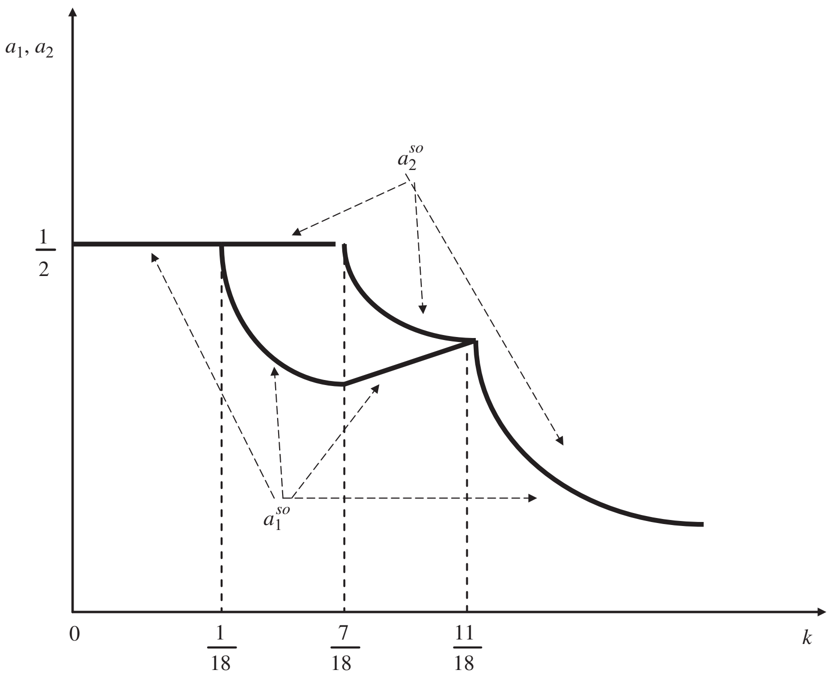

Fig. 6. Proposition 4 (endogenous pricing).

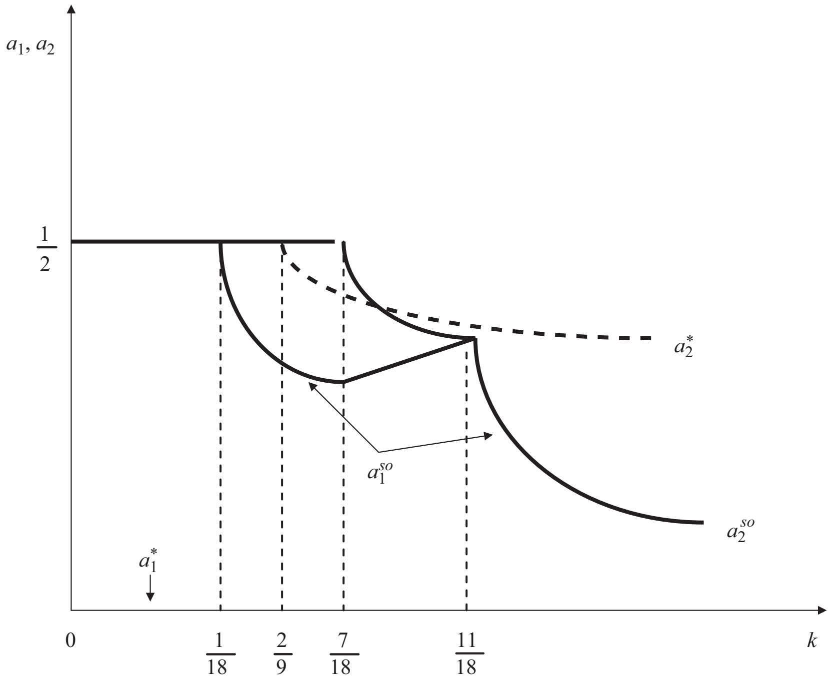

Fig. 7. Comparison between the Nash equilibrium and social optimum with endogenous pricing.

Corollary (*Contrasting equilibrium and social optimum with endogenous pricing*). *Firm* 1 (*low quality firm*) *acquires less information in equilibrium than is socially optimal given endogenous pricing. Firm* 2 (*high quality firm*) *acquires* (*weakly*) *less information in equilibrium than is socially optimal given endogenous pricing if and only if the cost of product customization is low.*

5. Brand name effects

We extend the core model by assuming that consumers are characterized by two attributes, their spatial location on the circle that captures aspects that either firm can customize, and their spatial location on a line that captures a preference for one firm's brand name over another. A consumer's brand name preference is uncorrelated with their preferred customizable product. On the "brand name" dimension, firm 1 is located at 0 and firm 2 is located at L, and consumer "brand name" preferences are uniformly distributed on $[0, L]$. This dimension captures consumer heterogeneity about the "brand name" that cannot be customized by the firms—a consumer who is located close to 0 prefers the brand name of firm 1. Firms do not know the brand name preferences of consumers, but as in our core model they can obtain information about customizable aspects of consumer preferences, or equivalently, provide a customization technology to consumers. The transportation cost along the brand name dimension is t, and the transportation cost on the customizable dimension (circle) is set equal to 1. The next proposition summarizes the equilibrium when there is sufficient heterogeneity over the non-customizable dimension.[18]

Proposition 5 (*Symmetric product-customization investments/information acquisition equilibrium*). *Assume that* $k \geqslant \frac{1}{6}$ *and let*

$$\bar{L} \equiv \frac{144k - 23 + \sqrt{10368k^2 - 3168k + 241}}{144tk},$$

where $\bar{L} \in [\frac{1}{12t}, \frac{2+\sqrt{2}}{2t}]$. *Then, for all* $L \geqslant \bar{L}$ *a symmetric PBE exists and is described as follows*:

- *Information*: $a_1^{**} = a_2^{**} = \frac{1}{12k} \leqslant \frac{1}{2}$.
- *Pricing*: $p_1^{**} = p_2^{**} = tL$.
- *Expected profits*: $\mathrm{E}\pi_1 = \mathrm{E}\pi_2 = \frac{tL}{2} - \frac{1}{144k}$.

The proof is omitted, but is available upon request. The central message of Proposition 5 is that when consumers differ significantly in non-customizable preferences, then firms make symmetric investments in product-customization technologies. The underlying economics is as follows. The non-customizable dimension reduces the price elasticity of consumer demand, which, in turn, reduces the intensity of price competition. This raises the relative value of learning more about the product characteristics each consumer likes—and to design a product that exploits that knowledge—leading both firms to customize. The game becomes a *prisoners' dilemma* with respect to product-customization decisions. Profits without product customization, i.e., when $\alpha_1 = \alpha_2 = 0$, are $\frac{tL}{2}$, which exceed those when product customization is feasible. Consumers are better off with customization, since they consume products that are closer to their ideal products and equilibrium prices are not affected. Furthermore, the equilibrium outcome of Proposition 5 is efficient. There are two potential sources of inefficiency: suboptimal levels of information acquisition/product customization and unequal prices. The optimal amount of consumer information is unaffected by the second dimension L. Therefore, the firms' decisions coincide with those of a regulator (see Lemma 3 when $k \geqslant \frac{5}{6}$, where $a_1^{so} = a_2^{so} = \frac{1}{12k}$). Moreover, due to symmetry, prices are equal and hence there are no pricing distortions. When $L = 0$, from Proposition 2, the equilibrium information acquisition is $a_1^* = 0$ and $a_2^* = \frac{3}{2(18k-1)}$. It can be easily verified that now one firm (firm 1) customizes more while the other (firm 2) customizes less, i.e., $a_2^* > a_2^{**}$.

It is useful to contrast the result in Proposition 5 with the predictions from standard spatial models such as Dos Santos Ferreira and Thisse (1996). In a duopoly setting where two firms are significantly spatially separated and must choose the level of their linear transportation costs before setting prices, Dos Santos Ferreira and Thisse show that the firms inefficiently choose the highest possible transportation cost—the *lowest* quality possible—in order to commit to reducing their price competition. In sharp contrast, here firms that are sufficiently distinguished in brand name make efficient, high quality information/product-customization choices. What drives the very different results is that in Dos Santos Ferreira and Thisse, the customers who gain the most from reduced travel costs are those who are farthest away, for whom inter-firm competition is fiercest, so that

[18] The analysis for $L \in (0, \bar{L})$ is tedious, and has the feature that customization investments are asymmetric but not necessarily maximally differentiated—basically "intermediate" to the cases that we analyze.

lowering transportation costs magnifies the competitive forces that drive prices down, reducing profits. In contrast, in our model, the consumers closest to a firm gain the most from better customization. This makes the provision of high quality customization attractive because a firm captures more of the customization rents, while increasing price competition by the smallest amount.

Proposition 5 also has a flavor of Irmen and Thisse's (1998) finding that in a multi-dimensional characteristics space, firms choose maximal differentiation in one dimension, and minimal differentiation in all other dimensions.[19] The intuition for their result is that ‘‘the cheapest’’ way (in terms of lost market share) to reduce price competition by any given amount is by targeting the dimension where demand is least elastic. In contrast, in our model, for *any* given levels of customization, firms always want to separate on the brand name dimension, because it improves their ability to extract rents from product customization—there is no imperfect substitution between different dimensions.

6. Conclusion

Our paper investigates the strategic investment in consumer-specific information by firms that can tailor products toward a consumer's ideal. The advent of the Internet and modern flexible production systems make an understanding of related economic issues increasingly important.

In a duopoly setting, we find that when brand name effects are weak, one firm refrains from engaging in effective product customization, while the other makes a significant investment, indeed acquiring perfect information if the costs of doing so are not too high. The firm that does not invest in product customization does so to avoid the fierce price competition that would emerge. The availability of consumer information benefits consumers, and the better-informed firm. The only clear loser is the firm acquiring minimal consumer information, which is hurt by its competitor's superior ability to target consumers.

We then find that when brand name effects are strong, both firms make significant investments in product-customization capabilities. The game becomes a prisoners' dilemma, because equilibrium prices under (costly) product customization do not change. Consumers again benefit from product customization, due to the better targeting of products, and total surplus is raised, as well. Thus, our paper has a strong point to make in the ongoing public debate about whether firms should be allowed to collect, share and use customer data (see the Report for Congress, ‘‘Internet Privacy: Overview and Pending Legislation,’’ www.epic.org, Feb. 6, 2003).[20] Our analysis indicates that—putting any privacy issues aside—such a practice will benefit consumers and therefore regulatory authorities should facilitate (and certainly not prohibit) the collection and application of consumer information in markets that fit our modeling assumptions.

It is always slightly risky to extrapolate from a static model to predict the behavior of firms when product-customization costs fall in the future. In industries such as PCs, where product characteristics are more important than brand names, one might expect Dell to continue to offer far more customization options than most of its rivals. So, too, Northwestern Mutual may distinguish itself from its rivals in the extent to which it tailors

[19]Relatedly, Syam et al. (2005) consider firms located on opposite diagonals of a unit square, and choose whether and which dimensions to perfectly customize, and show that they customize the same dimension.

[20]See also Liu and Serfes (2006).

insurance and investment advice, and IBM's consulting arm may do the same. Conversely, it may be that branding is sufficiently important in the shoe industry that Adidas may someday choose to mirror Nike's investment in product-customization capabilities. Finally, we observe that when brand names matter little, reductions in product-customization costs lead to greater investments in product customization or extensive product lines by at least one firm. However, this only raises total industry profits so long as such cost reductions do not induce firms to switch "investment regimes", so that firms move from asymmetric to symmetric investments in product customization. If a switching occurs, such improvements in product-customization capabilities will generate fiercer price competition that will drive industry profits down.

Acknowledgments

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Appendix A. Proofs

A.1. Proof of Proposition 1

To solve for equilibrium pricing we must first determine how the probability a consumer purchases firm i's product varies with the prices firms set, and the information investments firms make to target consumer's preferred products. Without loss of generality, we suppose that firm 2 acquires at least as much information about consumer preferences as firm 1, i.e., $a_2 \geqslant a_1$. Fig. A1 illustrates $\Pr_1 = \Pr(s_1 \leqslant s_2 + \frac{p_2 - p_1}{t})$. This probability is given by the proportion of the total area that is below the $s_1 = s_2 + \frac{p_2 - p_1}{t}$ line. Depending on the level of $\frac{p_2 - p_1}{t}$ relative to $a_2 - a_1$, there are three possibilities.

Case 1: $\frac{(p_2 - p_1)}{t} \geqslant (a_2 - a_1) \geqslant 0$. The top (dashed) line (in Fig. A1) illustrates this case, where the effective price premium, $\frac{(p_2 - p_1)}{t}$, exceeds the information quality difference, $a_2 - a_1$.

Case 2: $(a_2 - a_1) \geqslant \frac{(p_2 - p_1)}{t} \geqslant 0$. The middle (solid) line illustrates this case, where the effective price premium is a fraction of the information quality difference. This case holds in equilibrium.

Case 3: $(a_2 - a_1) \geqslant 0 \geqslant \frac{(p_2 - p_1)}{t}$. The bottom (starred) line illustrates this case, where firm 2 both acquires better information than firm 1 about consumers and charges a lower price.

Each case gives rise to a different expression for $\Pr_1$, and hence has to be analyzed separately. We first consider case 2, which, as we prove, is what emerges in equilibrium. In this case, firm 1's probability of winning the representative consumer (and consequently any consumer) is

$$\Pr_1 = \frac{\int_0^{\frac{1}{2} - a_2} \left(s_2 + \frac{p_2 - p_1}{t} \right) \mathrm{d}s_2}{(\frac{1}{2} - a_1)(\frac{1}{2} - a_2)} = \frac{(t - 2ta_2 + 4p_2 - 4p_1)}{2t(1 - 2a_1)}.$$

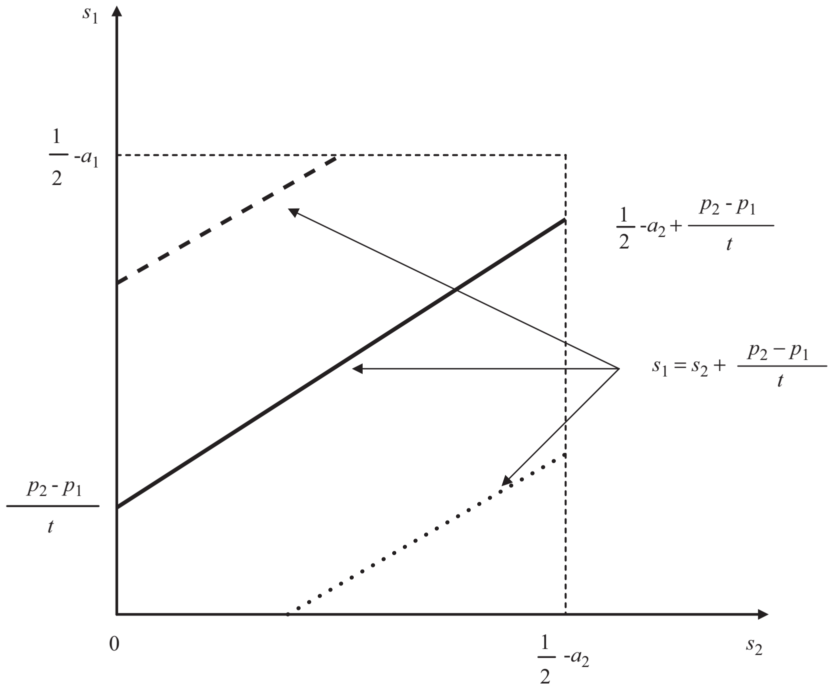

Fig. A1. $a_2 \geqslant a_1$.

Firm 1's expected profits are

$$E\pi_1(a_1, a_2, p_1, p_2) = p_1 \Pr_1 = \frac{p_1(t - 2ta_2 + 4p_2 - 4p_1)}{2t(1 - 2a_1)}. \tag{8}$$

Firm 2's expected profits are

$$E\pi_2(a_1, a_2, p_1, p_2) = p_2(1 - \Pr_1) = \frac{p_2(t - 4ta_1 - 4p_2 + 4p_1 + 2ta_2)}{2t(1 - 2a_1)}. \tag{9}$$

Firms choose p_1 and p_2 to maximize (8) and (9). The first-order conditions are

$$\frac{\partial \pi_1}{\partial p_1} = \frac{t - 2ta_2 + 4p_2 - 8p_1}{2t(1 - 2a_1)} = 0 \quad \text{and} \quad \frac{\partial \pi_2}{\partial p_2} = \frac{t - 4ta_1 - 8p_2 + 4p_1 + 2ta_2}{2t(1 - 2a_1)} = 0.$$

The second-order conditions are strictly satisfied. Hence, as long as in equilibrium $(a_2 - a_1) \geqslant \frac{p_2 - p_1}{t} \geqslant 0$, equilibrium pricing is given by the solution to the first-order conditions. Therefore, there is no need to check for a boundary equilibrium (i.e., $(a_2 - a_1) = \frac{p_2 - p_1}{t} \geqslant 0$, or $(a_2 - a_1) \geqslant \frac{p_2 - p_1}{t} = 0$, or $(a_2 - a_1) = \frac{p_2 - p_1}{t} = 0$) where first-order conditions are not satisfied with equality. The solutions to the first-order conditions are

$$p_1^* = t\left(\frac{1}{4} - \frac{a_1}{3} - \frac{a_2}{6}\right) \quad \text{and} \quad p_2^* = t\left(\frac{1}{4} - \frac{2a_1}{3} + \frac{a_2}{6}\right). \tag{10}$$

Consistent with the premise underlying case 2, effective equilibrium price differences are only a fraction of the information quality difference, $\frac{(p_2^* - p_1^*)}{t} = \frac{(a_2 - a_1)}{3}$. It remains to verify that given the pricing in Eq. (10) neither firm wants to alter its pricing so that one of the other "cases" holds.

The remaining of the proof is divided into two parts. We first demonstrate that a deviation from (10) that violates the assumptions of case 2 is unprofitable. We then show that (10) is unique by proving that an equilibrium in cases 1 and 3 does not exist.

Part 1 (*Existence*). Suppose a firm's deviation from (10) violates the condition of case 2. This puts us in case 1 or case 3. We present the probabilities of firm 1 making a sale in cases 1 and 3, respectively. These expressions are used repeatedly. This probability in case 1 is

$$\begin{aligned}\mathrm{Pr}_1 &= \frac{\int_0^{\frac{1}{2}-a_1-\frac{(p_2-p_1)}{t}}\left(s_2+\frac{p_2-p_1}{t}\right)\mathrm{d}s_2+\int_{\frac{1}{2}-a_1-\frac{(p_2-p_1)}{t}}^{\frac{1}{2}-a_2}\left(\frac{1}{2}-a_1\right)\mathrm{d}s_2}{\left(\frac{1}{2}-a_1\right)\left(\frac{1}{2}-a_2\right)} \\ &= \frac{(8ta_1p_2-8ta_1p_1-8t^2a_1a_2-t^2-4tp_2+4tp_1+4t^2a_1^2+4p_2^2-8p_1p_2+4p_1^2+4t^2a_2)}{-2t^2(1-2a_1)(1-2a_2)}.\end{aligned} \tag{11}$$

In case 3 it is

$$\begin{aligned}\mathrm{Pr}_1 &= \frac{\int_{-\frac{(p_2-p_1)}{t}}^{\frac{1}{2}-a_2}\left(s_2+\frac{p_2-p_1}{t}\right)\mathrm{d}s_2}{\left(\frac{1}{2}-a_1\right)\left(\frac{1}{2}-a_2\right)} \\ &= \frac{(8ta_2p_1-8ta_2p_2+t^2+4tp_2-4tp_1+4t^2a_2^2+4p_2^2-8p_1p_2+4p_1^2-4t^2a_2)}{2t^2(1-2a_1)(1-2a_2)}.\end{aligned} \tag{12}$$

Deviation by firm 1: Fix p_2 at p_2^* (see Eq. (10)). First assume that p_1 decreases by enough that $a_2-a_1<\frac{(p_2^*-p_1)}{t}$ (case 1). It can be easily verified (see Fig. A1) that Pr_1 in Eq. (3) exceeds Pr_1 given in (11) when case 1 holds (in this case the middle line goes above the top horizontal line of the box, as opposed to the top line which once it reaches the horizontal line of the box it stops increasing). We have already shown that when we use (3) instead of the correct expression, (11), then firm 1 does not want to deviate by lowering its price. Clearly, the incentive to cut price is even weaker if we replace (3) by the lower probability (11). Second, assume that p_1 increases so that $\frac{(p_2^*-p_1)}{t}<0$, and $\frac{(p_2^*-p_1)}{t}+\frac{1}{2}-a_2\geqslant 0$, i.e., we have moved to case 3. Then plugging p_2^* into (12) yields

$$\mathrm{Pr}_1^{\mathrm{dev}} = \frac{81t^2-180t^2a_2-144t^2a_1-216tp_1+160t^2a_1a_2+64t^2a_1^2+192ta_1p_1+100t^2a_2^2+240ta_2p_1+144p_1^2}{72t^2(1-2a_1)(1-2a_2)}.$$

The profit function is $\pi_1^{\mathrm{dev}}=p_1\mathrm{Pr}_1^{\mathrm{dev}}$. We find the maximum difference between profits after deviation and profits before deviation with respect to a_2. One can show that even in this most favorable scenario for firm 1 (where a_2 is chosen so that a deviation is the most profitable), this difference is zero.[21] Hence, such a deviation is also unprofitable. Third, assume that p_1 increases to the point that $\frac{(p_2^*-p_1)}{t}<0$ and $\frac{(p_2^*-p_1)}{t}+\frac{1}{2}-a_2<0$. This deviation is clearly unprofitable since firm 1's probability of making a sale falls to zero. Hence, firm 1 will not deviate from (10).

[21]The file with all the computations is available upon request.

Deviation by firm 2: Fix p_1 at p_1^* as it is given by (10). First, assume that p_2 decreases by enough that $\frac{(p_2-p_1^*)}{t} < 0$ (case 3). It can be easily verified (see Fig. A1) that $\Pr_2$ as it is given by (3) exceeds $\Pr_2$ as given by (12), when case 3 holds. We have already shown that when we use (3) instead of the correct expression given by (12), firm 2 does not want to deviate by lowering its price. Clearly, the incentive to cut price is even weaker if we replace (3) by the lower probability in (12). Second, assume that p_2 increases by enough that $a_2 - a_1 < \frac{(p_2-p_1^*)}{t}$ and $\frac{(p_2-p_1^*)}{t} - \frac{1}{2} + a_1 \leqslant 0$ (case 1). Plugging p_1^* into (11) yields

$$\Pr_1^{\text{dev}} = \frac{9t^2 - 144t^2a_1 - 216tp_2 + 108t^2a_2 + 256t^2a_1^2 + 384ta_1p_2 - 224t^2a_1a_2 + 144p_2^2 + 48tp_2a_2 + 4t^2a_2^2}{-72t^2(1-2a_1)(1-2a_2)}.$$

The profit function is $\pi_2^{\text{dev}} = p_2(1 - \Pr_1^{\text{dev}})$. It can be shown that such a deviation is not profitable.[22] Third, assume that p_2 increases to the point that $a_2 - a_1 < \frac{(p_2-p_1^*)}{t}$ and $\frac{(p_2-p_1^*)}{t} - \frac{1}{2} + a_1 > 0$. This deviation is clearly unprofitable since firm 2's probability of making a sale becomes zero. Hence, firm 2 will not deviate from (10) either.

Part 2 (*Uniqueness*). Given $a_2 \geqslant a_1$, we prove that the pair of equilibrium prices given by (10) is unique, by showing that an equilibrium in cases 1 and 3 does not exist.

A. *Case* 1: We first search for an equilibrium when $\frac{(p_2-p_1)}{t} > (a_2 - a_1) \geqslant 0$. The case where $\frac{(p_2-p_1)}{t} = (a_2 - a_1)$ was examined when we studied case 2 and therefore we can focus on interior solutions. Firm 1's probability of making a sale is given by (11). We differentiate $\pi_1 = p_1\Pr_1$ and $\pi_2 = p_2(1 - \Pr_1)$ with respect to p_1 and p_2, respectively. There are two solutions to $\frac{\partial \pi_2}{\partial p_2} = 0$,

$$p_2^* = \frac{t}{2} - ta_1 + p_1 \quad \text{and} \quad p_2^{**} = \frac{t}{6} - \frac{ta_1}{3} + \frac{p_1}{3}.$$

One can verify that if we use p_2^{**}, firm 1's first-order condition is never satisfied, i.e., $\frac{\partial \pi_1}{\partial p_1} = 1$. Therefore, we retain p_2^* and we obtain the following two solutions to firm 1's first-order condition,

$$p_1^* = \frac{5ta_1}{8} - \frac{5t}{16} \pm \frac{3t\sqrt{4a_1^2 - 20a_1 + 9 + 32a_1a_2 - 16a_2}}{16}.$$

The solution with the negative root yields negative values for the price for all permissible values of a_1 and a_2. Hence, we retain the solution with the positive root. But then routine calculation reveals that the assumption that $\frac{(p_2-p_1)}{t} > (a_2 - a_1)$ is violated. Therefore, there is no solution to the first-order conditions consistent with the assumptions of case 1.

B. *Case* 3: Now we search for an equilibrium when $(a_2 - a_1) \geqslant 0 > \frac{(p_2-p_1)}{t}$. The case where $\frac{(p_2-p_1)}{t} = 0$ was examined when we studied case 2 and therefore we can focus on interior solutions. Firm 1's probability of making a sale is given by (12). We differentiate $\pi_1 = p_1\Pr_1$ and $\pi_2 = p_2(1 - \Pr_1)$ with respect to p_1 and p_2, respectively. There are two solutions to $\frac{\partial \pi_1}{\partial p_1} = 0$,

$$p_1^* = \frac{t}{2} - ta_2 + p_2 \quad \text{and} \quad p_1^{**} = \frac{t}{6} - \frac{ta_2}{3} + \frac{p_2}{3}.$$

[22] The steps follow those for the deviation of firm 1 detailed above, and are available upon request.

It can be verified that if we use p_1^* firm 2's first-order condition is never satisfied, i.e., $\frac{\partial \pi_2}{\partial p_2} = 1$. Therefore, we retain p_1^{**} and we obtain the following two solutions to firm 2's first-order condition:

$$p_2^* = \frac{5ta_2}{8} - \frac{5t}{16} \pm \frac{3t\sqrt{4a_2^2 - 20a_2 + 9 + 32a_1a_2 - 16a_1}}{16}.$$

The solution with the negative root yields negative values for the price for all permissible values of a_1 and a_2. Hence, we retain the solution with the positive root. But then routine calculation again reveals that the assumption that $0 > \frac{(p_2 - p_1)}{t}$ is violated. Therefore, there is no solution to the first-order conditions consistent with the assumptions of case 3.

A.2. Proof of Proposition 2

We have already proven that a symmetric interior solution is not an equilibrium. Hence, we have to search for an asymmetric interior or a boundary solution. We examine the following cases.

1. $(a_1 = a_2 = 0)$. Let us look at firm 2's incentive to deviate by increasing a_2 infinitesimally. Differentiating (2) with respect to a_2 and evaluating the derivative at $(0, 0)$ yields

$$\frac{\partial \mathrm{E}\pi_2(0,0)}{\partial a_2} = \frac{t}{6} > 0.$$

Hence, firm 2 has an incentive to acquire better information.

2. $(a_1 = 0$ and $a_2 = \frac{1}{2})$ and $(a_2 = a_1 = \frac{1}{2})$. Second, we check whether $a_1 = 0$ and $a_2 = \frac{1}{2}$ or $a_2 = a_1 = \frac{1}{2}$ are an equilibrium. The first derivatives of the profit functions (i.e., (1) and (2)) are

$$\frac{\partial \mathrm{E}\pi_1(a_1, \frac{1}{2})}{\partial a_1} = -\frac{t(1 + 18ka_1)}{9} < 0 \quad \text{and} \quad \frac{\partial \mathrm{E}\pi_2(0, a_2)}{\partial a_2} = \frac{t(3 + 2a_2 - 36ka_2)}{18}.$$

Thus, firm 1's best response to $a_2 = \frac{1}{2}$ is $a_1 = 0$. This proves that $a_2 = a_1 = \frac{1}{2}$ cannot be an equilibrium. If $k \leqslant \frac{2}{9}$, then $\frac{\partial \mathrm{E}\pi_2(0,a_2)}{\partial a_2} \geqslant 0$, which implies that firm 2's best response to $a_1 = 0$ is $a_2 = \frac{1}{2}$. Since a_1 and a_2 have attained extreme values, the assumed structure (i.e., $a_2 \geqslant a_1$) cannot change. Hence, $a_1 = 0$ and $a_2 = \frac{1}{2}$ is an equilibrium when $k \leqslant \frac{2}{9}$.

3. $(a_1 = 0$ and $a_2 = \frac{3}{2(18k-1)} < \frac{1}{2})$ and $(0 < a_1 < \frac{1}{2}$ and $0 < a_2 < \frac{1}{2})$. When $k > \frac{2}{9}$, $a_1 = 0$ and $a_2 = \frac{1}{2}$ is not an equilibrium. In this case the equilibrium is $a_1 = 0$ and $a_2 = \frac{3}{2(18k-1)}$. To see why, evaluate the first derivative of firm 2's profit function at $a_1 = 0$,

$$\frac{\partial \mathrm{E}\pi_2(0, a_2)}{\partial a_2} = \frac{t(3 + 2a_2 - 36ka_2)}{18} = 0 \implies a_2 = \frac{3}{2(18k-1)} < \frac{1}{2}.$$

Since $a_1 = 0$, a_2 cannot change the assumed structure (i.e., $a_2 \geqslant a_1$). Now differentiate firm 1's profit function with respect to a_1. This yields,

$$\frac{\partial \mathrm{E}\pi_1(a_1, a_2)}{\partial a_1} = \frac{t(16a_1 - 16a_1^2 - 4a_2 - 3 + 4a_2^2 - 72ka_1 + 288ka_1^2 - 288ka_1^3)}{36(1 - 2a_1)^2}.$$

We show that $\frac{\partial \mathrm{E}\pi_1(a_1,a_2)}{\partial a_1} < 0$, for any a_1 and a_2 such that $\frac{1}{2} > a_2 \geqslant a_1$. We set $k = 0$ and we solve the above first-order condition with respect to a_2. We obtain the following two roots:

$$a_2^1 = -\tfrac{1}{2} + 2a_1 \quad \text{and} \quad a_2^2 = \tfrac{3}{2} - 2a_1.$$

The first-order condition is negative if $a_2 \in (a_2^1, a_2^2)$. It can be easily verified that $a_2 \in (a_2^1, a_2^2)$ for $a_1 \in [0, \frac{1}{2})$. Therefore, and since $a_2^2 > \frac{1}{2} > a_2 \geqslant a_1 > a_2^1$, when $\frac{1}{2} > a_2 \geqslant a_1$, we must have $\frac{\partial \mathrm{E}\pi_1(a_1,a_2)}{\partial a_1} < 0$. Now we show that $\frac{\partial \mathrm{E}\pi_1(a_1,a_2)}{\partial a_1}$ decreases as k increases, which implies that the first-order condition remains negative for all $k > 0$,

$$\frac{\partial^2 \mathrm{E}\pi_1(a_1,a_2)}{\partial a_1 \partial k} = -2ta_1 < 0.$$

Hence, firm 1's best response to any a_2, provided that $\frac{1}{2} > a_2 \geqslant a_1$, is $a_1 = 0$. This proves that $0 < a_1 < \frac{1}{2}$ and $0 < a_2 < \frac{1}{2}$ (i.e., an interior outcome; not necessarily symmetric) is never an equilibrium. But firm 1 can also choose $a_1 > a_2 = \frac{3}{2(18k-1)}$ (since a_2 now is strictly less than $\frac{1}{2}$). To check this deviation we use the symmetric counterpart of Eq. (1), which is derived by assuming that $a_1 \geqslant a_2$. Under this assumption, firm 1's profit function is

$$\mathrm{E}\pi_1 = \frac{t(-8a_2 + 2a_1 + 3)^2}{72(1-2a_2)} - tka_1^2.$$

We differentiate $\mathrm{E}\pi_1$ with respect to a_1 and evaluate the derivative at $a_2 = \frac{3}{2(18k-1)}$,

$$\frac{\partial \mathrm{E}\pi_1\left(a_1, \dfrac{3}{2(18k-1)}\right)}{\partial a_1} = \frac{t(180ka_1 - 2a_1 - 15 + 54k - 648k^2a_1)}{36(9k-2)}.$$

This derivative is zero at $a_1 = \frac{3(18k-5)}{2(324k^2-90k+1)}$. But, it can be easily checked that $a_1 < a_2$ for $k > \frac{2}{9}$. Hence, the optimal a_1, assuming that $a_1 \geqslant a_2$, must be either equal to a_2 or equal to $\frac{1}{2}$, i.e., at one of the two boundaries. The second derivative is negative if and only if $k > \frac{5+\sqrt{21}}{36} > \frac{2}{9}$, which implies that firm 1's profit function becomes concave only when k exceeds a threshold. First, deviating to $a_1 = a_2 < \frac{1}{2}$, as we have already shown above, is not optimal, as it is dominated by setting $a_1 = 0$. Second, firm 1 can deviate to $a_1 = \frac{1}{2}$. It can be routinely verified that $a_1 = 0$ yields higher profits to firm 1 than $a_1 = \frac{1}{2}$, when $k \geqslant \frac{2}{9}$. Hence, no such deviations are profitable either.

A.3. Proof of Lemma 3

First, note that $a_2 = \frac{1}{2}$ and $a_1 > 0$ cannot be optimal, if $k > 0$. This is because the expected disutility is already zero if we set $a_2 = \frac{1}{2}$ and there is no need to incur the cost to increase the precision of the other signal. We differentiate C (see (6)) with respect to a_1 and a_2,

$$\frac{\partial C}{\partial a_1} = \frac{t(4a_2 - 1 + 12ka_1 - 48ka_1^2 + 48ka_1^3 - 4a_2^2)}{6(1-2a_1)^2} \quad \text{and}$$

$$\frac{\partial C}{\partial a_2} = \frac{t(6a_1 - 4a_2 + 12ka_2 - 24ka_1a_2 - 1)}{6(1-2a_1)}.$$

Clearly, $a_2 = a_1 = 0$ cannot be optimal, because both first-order conditions evaluated at this point are strictly negative and the social planner can lower the social inefficiency by acquiring more information. Moreover, it can be easily verified that $\frac{\partial C}{\partial a_1}|_{a_1=0} < 0$, when

$a_2 < \frac{1}{2}$. This implies that $a_1 = 0$ and $a_2 < \frac{1}{2}$ cannot be a solution. Therefore, there are two types of solutions left: interior ($\frac{1}{2} > a_1 > 0$ and $\frac{1}{2} > a_2 > 0$) and corner ($a_1 = 0$ and $a_2 = \frac{1}{2}$). There are three solutions to the first-order conditions:

$$a_1^* = \frac{1}{12k} \quad \text{and} \quad a_2^* = \frac{1}{12k},$$

$$a_1^{**} = \frac{12k - 5 + \sqrt{24k - 11}}{24k} \quad \text{and} \quad a_2^{**} = \frac{-8k + 5 - \sqrt{24k - 11}}{4k(1 - \sqrt{24k - 11})},$$

$$a_1^{***} = \frac{12k - 5 - \sqrt{24k - 11}}{24k} \quad \text{and} \quad a_2^{***} = \frac{-8k + 5 + \sqrt{24k - 11}}{4k(1 + \sqrt{24k - 11})}.$$

First, we show that the second solution is not valid. a_2^{**} is less than $\frac{1}{2}$, if and only if $k > \frac{3}{2}$. But if $k > \frac{3}{2}$, $a_2^{**} < a_1^{**}$, contradicting the assumption that $a_2 \geqslant a_1$. There are three candidate solutions;

$$a_2 = \frac{1}{2} \quad \text{and} \quad a_1 = 0 \quad \text{(corner)}, \tag{13}$$

$$a_1 = \frac{12k - 5 - \sqrt{24k - 11}}{24k} \quad \text{and}$$
$$a_2 = \frac{-8k + 5 + \sqrt{24k - 11}}{4k(1 + \sqrt{24k - 11})} \quad \text{(asymmetric interior)}, \tag{14}$$

$$a_1 = \frac{1}{12k} \quad \text{and} \quad a_2 = \frac{1}{12k} \quad \text{(symmetric interior)}. \tag{15}$$

We substitute (13), (14) and (15) into C to obtain

$$C^1 = \frac{tk}{4} \quad \text{(corner)},$$

$$C^2 = \frac{t(2k\sqrt{24k - 11} - \sqrt{24k - 11} + 94k - 23 - 84k^2 + 12k^2\sqrt{24k - 11})}{48k(1 + \sqrt{24k - 11})}$$
(asymmetric interior),

$$C^3 = \frac{t(12k - 1)}{72k} \quad \text{(symmetric interior)}.$$

It can be readily verified that

1. If $k < \frac{1}{2}$, $\min\{C^1, C^2, C^3\} = C^1$. At $k = \frac{1}{2}$, $C^1 = C^2 = \frac{t}{8} < C^3 = \frac{5t}{36}$.
2. If $k \in (\frac{1}{2}, \frac{5}{6})$, $\min\{C^1, C^2, C^3\} = C^2$. At $k = \frac{5}{6}$, $C^2 = C^3 = \frac{3t}{20} < C^1 = \frac{5t}{24}$.
3. If $k > \frac{5}{6}$, $\min\{C^1, C^2, C^3\} = C^3$.

References

Åhlström, P., Westbrook, R., 1999. Implications of mass customization for operations management. International Journal of Operations and Production Management 19, 262–274.

Anderson, S.P., de Palma, A., 1988. Spatial price discrimination with heterogeneous products. Review of Economic Studies 55, 573–592.

Bergin, J., Bernhardt, D., 1992. Anonymous sequential games with aggregate uncertainty. Journal of Mathematical Economics 21, 543–562.
Bernhardt, D., Massoud, N., 2006. ATM provision. Working paper.
Chen, Y., 1997. Paying customers to switch. Journal of Economics and Management Strategy 6, 877–897.
Chen, Y., 2006. Marketing innovation. Journal of Economics and Management Strategy 15, 101–123.
Chen, Y., Iyer, G., 2002. Consumer addressability and customized pricing. Marketing Science 21, 197–208.
Choi, S.-Y., Stahl, D.O., Whinston, A.B., 1997. The Economics of Electronic Commerce. Macmillan Technical Publishing.
Dewan, R., Jing, B., Seidmann, A., 2000. Adoption of Internet-based product customization and pricing strategies. Journal of Management Information Systems 17, 9–28.
Dewan, R., Jing, B., Seidmann, A., 2003. Product customization and price competition on the Internet. Management Science 49, 1055–1070.
Dos Santos Ferreira, R., Thisse, J.-F., 1996. Horizontal and vertical differentiation: The Laundhardt model. International Journal of Industrial Organization 14, 485–506.
Feldman, M., Gilles, C., 1985. An expository note on individual risk without aggregate uncertainty. Journal of Economic Theory 35, 26–32.
Fudenberg, D., Tirole, J., 2000. Customer poaching and brand switching. RAND Journal of Economics 31, 634–657.
Gal-Or, E., Gal-Or, M., 2005. Customized advertising via a common media distributor. Marketing Science, 241–253.
Ghose, A., Huang, K.-W., 2005. Personalized pricing and quality customization. Working paper, New York University.
Irmen, A., Thisse, J.-F., 1998. Competition in multi-characteristics spaces: Hotelling was almost right. Journal of Economic Theory 78, 76–102.
Kotha, S., 1996. From mass production to mass customization: The case of the national industrial bicycle company of Japan. European Management Journal 14, 442–450.
Kretschmer, T., 2005. Competing technologies in the Database Management Systems Market. Working paper #05-17, NET Institute, NYU Stern.
Liu, Q., Serfes, K., 2004. Quality of information and oligopolistic price discrimination. Journal of Economics and Management Strategy 13, 671–702.
Liu, Q., Serfes, K., 2006. Customer information sharing among rival firms. European Economic Review 50, 1571–1600.
Norman, G., Pepall, L., Richards, D., 2001. Versioning, brand stretching, and the evolution of e-commerce markets. Working paper.
Piller, F.T., Möslein, K., 2002. From economies of scale towards economies of customer interaction: Value creation in mass customization based electronic commerce. In: 15th Bled Electronic Commerce Conference–eReality: Constructing the eEconomy, Bled, Slovenia, June 17–19, 2002.
Salop, S.C., 1979. Monopolistic competition with outside goods. Bell Journal of Economics 10, 141–156.
Shaffer, G., Zhang, Z.J., 2000. Pay to switch or pay to stay: Preference-based price discrimination in markets with switching costs. Journal of Economics and Management Strategy 9, 397–424.
Shaked, A., Sutton, J., 1982. Relaxing price competition through product differentiation. The Review of Economic Studies 49, 3–14.
Syam, N.B., Ruan, R., Hess, J.D., 2005. Customized products: A competitive analysis. Marketing Science 24, 569–584.
Thisse, J.-F., Vives, X., 1988. On the strategic choice of spatial price policy. American Economic Review 78, 122–137.
Vickery, S., Dröge, C., Germain, R., 1999. The relationship between product-customization and organizational structure. Journal of Operations Management 17, 377–391.
Weiber, R., Kollmann, T., 1998. Competitive advantages in virtual markets—perspectives of ‘information-based marketing’ in cyberspace. European Journal of Marketing 32, 603–615.