Is Personalized Pricing Profitable When Firms Can Differentiate?

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We consider the role of personalized pricing (PP) on product differentiation when PP is costly to implement. Employing a stylized yet commonly-used formulation, we find that when firms decide on positioning before deciding on PP implementation, PP implementation cost affects not only the amount of differentiation firms choose in their positioning, firm profits, consumer surplus, and social welfare, but also whether firms implement PP. When PP implementation cost is low, firms cannot help but to implement PP and engage in direct price competition. Moreover, firms implementing PP reduce their differentiation, further intensifying price competition, and are worse off. When PP implementation cost is moderate, firms position to reduce their differentiation to commit to not implementing PP, again aggravating price competition. In contrast, when PP implementation cost is higher, firms increase their differentiation due to the threat of PP but do not implement PP. As a result, the availability of PP improves firm profits, even though firms do not implement PP. However, if differentiation is restricted, then PP availability cannot improve firm profits. If an information seller sets the PP implementation cost, then it sets the cost low. Consequently, firms implement PP and are worse off. We also find that when firms decide whether to implement PP before deciding on positioning, they never implement PP. This is the case when PP implementation is complex and differentiation can be affected by short-run advertising and promotion. Finally, we show that banning PP can benefit consumers when accounting for changes in firm positioning.

Keywords: Personalized pricing, data analytics, information technology, price discrimination, differentiation, competition.

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1. Introduction

With advances in information technology, firms across a wide array of industries collect, store, and analyze detailed consumer digital footprints to charge different prices to different individuals. In 2012, the Wall Street Journal identified that *"several companies, including Staples, Discover Financial Services, Rosetta Stone Inc. and Home Depot Inc., were consistently adjusting prices based on a range of characteristics that could be discovered about the user."* For instance, Staples charged a consumer $15.79 for a Swingline stapler, but only $14.29 to another consumer who is located a few miles away for the same stapler. Office Depot also admitted that it *"uses customers' browsing history and geolocation"* to customize its price offers (Valentino-Devries et al. 2012). Travel reservation sites such as Orbitz, Priceline, and CheapTickets often give discounts to specific users based on their personal information (Hannak et al. 2014). Orbitz collects data such as zip code, type of browser, and even type of device to offer customized prices to visitors. For example, Mac users are charged higher prices than their PC-using counterparts (Mattioli 2013). As Bill Gates commented, *"Sellers will use technology to extract the highest price they can from a particular shopper,"* and *"This is an extension of pricing practices that are common today"* (Woolley 1998). These strategies are so effective that, according to Steve Burd, the CEO of Safeway, *"There's going to come a point where our shelf pricing is pretty irrelevant because we can be so personalized in what we offer people"* (Choi 2013).

Personalized pricing (PP) allows firms to offer individualized prices to consumers based on knowledge of their willingness to pay. Although existing literature has extensively studied the effects of PP on the price competition between firms (e.g., Thisse and Vives 1988, Bester and Petrakis 1996, Ghose and Huang 2009), less is known about whether implementing PP is profitable when changes in positioning and hence differentiation are also possible. For instance, given that Staples and Office Depot can create specific offers for their consumers at a cost, would these retailers try to locate their stores closely together or far apart? Given that both Orbitz and Priceline can collect consumers' data and charge them personalized prices based on their digital footprints, should Orbitz and Priceline differentiate from each other by offering different but equivalent user interfaces and design (e.g., using a more functional search engine interface vs. adopting a more visual interface)?

We seek to answer these questions by modeling firms' PP implementation decisions and positioning decisions so that differentiation is endogenized in our formulation. We assume that implementing PP requires a fixed cost such as investing in a database that together with analytics is capable of PP. Within this setup, we analyze the effect of PP implementation cost on firms' positioning and PP implementation decisions. Although existing literature shows that PP intensifies price competition and leads to a form of the prisoner's dilemma, it is not *a priori* clear how this effect changes when firms endogenously choose their relative positions and make their PP implementation decisions.

In line with the literature, we consider a stylized yet commonly-used model with two differentiated firms competing in a market. Each firm chooses its own position on a Hotelling line where the positioning relative to each other is the measure of differentiation. After observing each other's positioning decisions, each firm decides whether to implement PP at a cost. If a firm implements PP, then it can distinguish among consumers and offer them personalized prices; otherwise, it offers a standard, non-discriminatory price to all consumers. Finally, firms choose their prices and consumers make purchase decisions to maximize their utility.

Our model yields several noteworthy results. First, consistent with prior work, we find that when the cost of implementing PP is low, firms cannot help but implement PP and engage in direct price competition, which works to the detriment of both firms' profits. However, separate from what has been found in prior work, we find that when firm positions are endogenized, yet another peril arises from PP. Firms, attempting to remain competitive, narrow their differentiation, which further intensifies price competition and leaves the firms worse off. This is because, under PP, firms have stronger incentives to position themselves closer to the center of the Hotelling interval to reduce the average distance between themselves and their consumers. As a result, both firms narrow their differentiation. And, so, firms trap themselves in a prisoner's dilemma: Though they are better off without PP, they cannot help but implement PP and compete directly in prices in equilibrium. This result is consistent with the observation that Priceline and Orbitz compete fiercely in the online travel agent market (Hussey 2021).

Second, when the cost of implementing PP is moderate, firms are able to avoid implementing PP, but we find that they must narrow their differentiation in order to commit to not doing so. This result arises because the benefit from PP increases with the firms' differentiation. Thus, the threat of implementing PP decreases firm differentiation, again aggravating price competition and driving down firm profits. We also find that, within this regime, a decline in PP implementation cost can reduce differentiation and hurt firm profits.

Third, when the cost of implementing PP is high, we find that firms no longer need to narrow their differentiation to commit to not implementing PP. In stark contrast to the established findings that PP intensifies market competition and erodes firm profits, we find that, within certain circumstances, the threat of implementing PP causes firms to widen their differentiation, which in turn alleviates price competition and, as a result, leaves them better off. Thus, the availability of PP can improve firm profits even though they do not implement PP. Within the same sequence of decisions we also find that if an information seller sets the PP implementation cost, then it sets the cost low, firms implement PP and are worse off.

In addition, we consider an alternative scenario in which firms decide whether to implement PP before deciding on their relative positions to establish differentiation. This scenario corresponds to cases in which firms can widen or narrow their differentiation in the short-run – possibly through advertising and promotions of different kinds – but PP implementation requires a longer-term investment such as may be the case with database development along with dynamic pricing software. We show that, in this scenario, firms never implement PP even if it is costless to do so and, thus, they escape the prisoner's dilemma. This occurs because if a firm implements PP, then the rival firm chooses to reduce differentiation, which intensifies price competition and erodes profits. Here it is the threat of reduced differentiation that precludes PP implementation. Finally, we find that when the cost of implementing PP is low and accounting for firm positioning, then a policy of banning PP can increase firm profits and reduce consumer surplus and social welfare, whereas the reverse occurs if PP implementation costs are high.

2. Related Literature

Our work contributes to the literature on PP. Several articles have studied PP in a competitive market and show how it affects firms' profits. Although it is obvious that PP benefits a monopolistic firm by allowing it to extract consumer surplus through first-degree price discrimination (Elmachtoub et al. 2021), the case is more complicated under market competition. Thisse and Vives (1988) consider a market in which competing firms choose between PP and uniform pricing. They show that in the unique subgame perfect equilibrium, both firms choose PP because it gives them more flexibility to respond to rival actions and make them more capable in competition. However, due to the intense competition PP unleashes, this equilibrium constitutes a form of the prisoner's dilemma and, as such, firm profits are higher when they both choose uniform pricing. Bester and Petrakis (1996) and Choudhary et al. (2005) examine one-to-one promotions and other forms of PP and find that PP generally leads to the same result: The prisoner's dilemma in which all firms are worse off compared to the case where they cannot implement PP. With that being said, in certain cases PP may not lead to a prisoner's dilemma. Shaffer and Zhang (2002) take firm heterogeneity into account and find that PP may benefit a firm with a higher-quality product. Ghose and Huang (2009) incorporate quality improvement efforts into duopoly competition with PP and find that even symmetric firms can be better off with PP. Finally, Matsumura and Matsushima (2015) uncover that firms may forfeit PP when they engage in marginal cost-reducing activities after they decide whether to implement PP. We show that when implementing PP is costly and firms make both their positioning and PP implementation decisions, competing firms can be better off with the availability of PP, a result that is a new addition to the PP literature.

There are also several studies that investigate the interaction between PP and product differentiation. For instance, Anderson and de Palma (1988) study a setting in which firms implement

PP with heterogeneous products and face a logit demand function. They show that firms choose central agglomeration when their products are highly differentiated. de Fraja and Norman (1993) extend the work of Anderson and de Palma (1988) to linear demand and obtain similar results. Eber (1997) shows that for any level of product differentiation, there exists an equilibrium in which both firms engage in PP, thereby leading to a form of the prisoner's dilemma. However, Eber (1997) does not endogenize the firms' location choice. Colombo (2011) considers a setting in which competing firms choose both their locations and the pricing scheme. He shows that both firms choose PP when they choose their locations first and price discrimination is relatively precise. Different from the above literature, we incorporate the firms' cost of implementing PP and show that this cost has substantial effects on location choice as well as pricing decisions.

PP also bears similarities to behavior-based pricing (BBP), which is the practice of keeping track of consumers' purchase histories and conditioning price offerings accordingly. BBP differs from PP from the following perspectives. First, under PP, a firm has direct access to a consumer's exact willingness to pay for its product and charges each consumer an individual-specific price. Whereas under BBP, a firm only knows a consumer's purchase history and charges the consumer a segment-specific price accordingly (old vs. new consumers). Second, under PP, the firms' data is exogenously given whereas under BBP, consumers endogenously make their purchase decisions, which then becomes the firms' data. Given the above difference, the PP literature typically studies a single-period model while the BBP literature uses multi-period models assuming that firms learn about consumer valuations over time. Like PP, BBP can also lead to a form of the prisoner's dilemma (Villas-Boas 1999, Fudenberg and Tirole 2000) because it encourages competing firms to poach each other's consumers. With purchase histories, competition becomes more intense, and as a result, total firm profits decline from what they would have been without BBP. Zhang (2011) shows that, when firms customize the horizontal attributes of products, profits become even lower than when firms only practice BBP. Aloysius et al. (2013) find that a form of sequential pricing – one in which a firm revises the price of a second good after a consumer has made their initial purchase decision – can increase profits relative to other methods such as mixed bundling. Choe et al. (2018) consider a BBP model where firms offer customized prices to their own previous consumers. Again, they find that customized pricing intensifies market competition and renders both firms worse off. Fudenberg and Villas-Boas (2006) provide a comprehensive review of BBP and consumer recognition. Our model differs from BBP because, under BBP, a firm only knows consumers' purchase histories and offers two prices to old and new consumers. Under PP, however, a firm knows the consumers' exact willingness to pay and can charge each consumer a customized price. Moreover, we endogenize the firms' decision to implement PP, an issue that is not studied in the BBP literature.

3. The Model

We consider a market with a continuum of consumers that are uniformly distributed along a Hotelling interval between 0 and 1. Two competing firms in the market are denoted by A and B. Let x_A and x_B denote firm positions; later, we model firm positioning decisions. Following the literature on product differentiation (Sajeesh and Raju 2010), we assume that the firms can position themselves outside the Hotelling interval since, as Tyagi (2000) notes using a geographical interpretation of the Hotelling line, *"Even though all consumers may be located in a city, firms can locate their shopping malls outside the city"* (p.931). Going further and concentrating specifically on differentiation, Zhang (2011) suggests that firms' *"products may contain features that all consumers find undesirable; firms may even introduce 'nuisance attributes' for differentiation purposes."* (p.175). Nonetheless, in Section 7.1, we investigate the case in which the firms are restricted to positioning themselves within the Hotelling interval.

Each consumer has a unit demand, which can be satisfied by firm A or B. All consumers have reservation value v. We assume that v is sufficiently large to ensure that the market is covered, that is, demand is for a necessary good. This assumption is common in the literature and allows us to focus on the effects of competition.

A consumer experiences a disutility due to misfit when procuring a good or service from a firm that is located at a "distance" from their ideal point, the latter which is their location on the interval. We assume that the misfit cost is quadratic in the distance between the consumer's ideal point and each firm. That is, a consumer located at x experiences a disutility $t(x-x_j)^2$ when consuming from firm $j \in \{A, B\}$, where $t > 0$ captures the extent of taste heterogeneity. The assumption of a quadratic misfit cost – often characterized as a transportation cost – is also common in the literature (Liu and Tyagi 2011, Tyagi 2000, Zhang 2011) and guarantees that a pure strategy equilibrium always exists in the pricing subgame. As d'Aspremont et al. (1979) point out, under a linear misfit/transportation cost a pure strategy pricing equilibrium may not exist when firms are positioned closely together.

In our model setup, a PP technology allows the firms to price-target consumers. If a firm implements PP, then it learns about the preferences (exact location on the Hotelling line) of every consumer and can tailor its price offerings accordingly. More specifically, a firm chooses between two options. If the firm does not implement PP, then it cannot distinguish between the consumers and, therefore, offers a uniform price to all consumers. Alternatively, if the firm implements PP, then it offers a targeted price $p(x)$ to consumers located at x. PP comes in many forms such as promotions offered to consumers based on their digital footprint. Our model assumes that when implementing PP, a firm obtains perfect information of consumer preferences. This is clearly a mathematical assumption rather than a reflection of reality as firms' information is usually imperfect. Nonetheless, we view our model as a useful limiting case and expect our qualitative results to hold when targeting information is sufficiently accurate. In Section 7.2 we examine the case when information on consumer preferences is imperfect.

PP is, of course, costly to implement, and so we let $F \geq 0$ denote the fixed cost of doing so. For instance, as mentioned above, consumers have lower willingness to pay when they are far away from a firm's physical store. In this case, a firm can acquire consumers' willingness to pay information by purchasing their geo-location data from data vendors or investing in information technologies that are capable of collecting such data. Traveling websites such as Orbitz can make inferences of consumers' preferences by purchasing or collecting their personal information such as browsing history and device information, which is, of course, costly to the firms.[1] Our assumption of costly information acquisition is consistent with the observation that *"sellers invest many millions of dollars in computer systems to collect data"* (Acquisti and Varian 2005) (p. 373).

The game unfolds in three stages as seen in Figure 1. In the first stage, the firms simultaneously choose their positions, $x_A, x_B \in R$. In the second stage, the firms simultaneously decide whether to implement PP. If a firm implements PP, then it incurs the implementation cost F and can price-target consumers. If a firm forgoes PP in this stage, then it cannot implement PP at a later stage. In this setting, we assume the firms make positioning decisions which establish their differentiation prior to making their PP implementation decisions. This is a sequence that is congruent with the observation that certain positioning decisions such as physical location, website design, payment options, and features of their goods or services are usually longer-term decisions whereas PP can be implemented in the short-run such as using limited time promotions supported by consumer information purchased from a third party (Taylor 2004). In Section 6 we consider the alternative scenario in which PP decisions are made prior to the positioning decisions.

In the third stage, the firms choose prices for their consumers. As noted in the second stage, if firm j implements PP, it charges a targeted price $p_j(x)$ to consumers located at x. Otherwise, firm j does not implement PP and charges a uniform price p_j to all consumers. We assume that if only one firm implements PP, then the firm without PP chooses its price first. Such timing is, again, common in existing literature (Thisse and Vives 1988, Shaffer and Zhang 2002, Choudhary et al. 2005, Matsumura and Matsushima 2015, Choe et al. 2018), which assumes that firms choose their targeting strategies and promotional prices after choosing their regular (i.e., uniform) prices. This reflects the view that a firm's regular price is a menu price that is sticky whereas promotional

[1] Strictly speaking, a firm must also know the relationship between consumers' willingness to pay and personal data to implement PP. The firm can gain such relationships through market research, small-scale experiments or purchasing analytics tools from third parties (e.g., large online platforms who already has done such research).

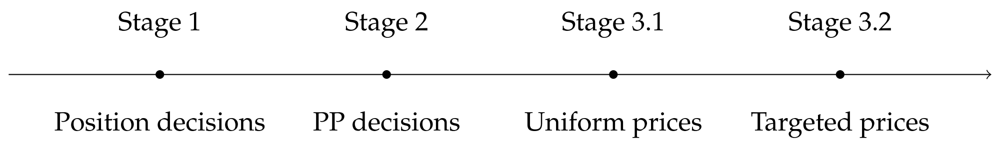

Figure 1 Timing of the model

offers, such as via targeted coupons, can be adjusted easily and dynamically.[2] When both firms implement or neither firm implements PP, they choose their prices simultaneously.

It is worth noting that although we assume that the firms can offer personalized prices to consumers, they do not offer personalized products to consumers, possibly because it is too costly to do so. For instance, using Staples and Office Depot as an example, these firms are not able to change their store locations for different consumers. Likewise, Orbitz and Priceline offer their same user interface to all consumers. Of course, there exist scenarios where the firms can customize both their products and prices based on consumer data, which is beyond the scope of the present work.

4. A Uniform Pricing Benchmark

Before proceeding, consider a benchmark in which PP is banned by law or is infeasible; in other words, both firms use uniform pricing. One may imagine a conventional market in which consumer data or technologies for PP are unavailable for firm access and use. We use backward induction to find the subgame perfect equilibrium.

Stage 3: Consider the subgame after the firm positions $x_A^{\varnothing}$ and $x_B^{\varnothing}$ are chosen, where the superscript $\varnothing$ represents the infeasibility of PP. Without loss of generality, we locate firm A on the left, i.e., $x_A^{\varnothing} \leq x_B^{\varnothing}$. In the third stage, the two firms simultaneously choose their uniform prices $p_A^{\varnothing}$ and $p_B^{\varnothing}$. Given their prices and positions, we can identify the location of the indifferent consumer, $x_0^{\varnothing}$, that obtains the same utility from purchasing either product:

$$v - p_A^{\varnothing} - t(x_A^{\varnothing} - x_0^{\varnothing})^2 = v - p_B^{\varnothing} - t(x_B^{\varnothing} - x_0^{\varnothing})^2,$$

[2] If both uniform and targeted prices are set simultaneously, then no pure strategy equilibrium exists in the pricing subgame.

which yields that $x_0^{\varnothing} = (p_A^{\varnothing} - p_B^{\varnothing} + t x_A^{\varnothing 2} - t x_B^{\varnothing 2})/(2t(x_A^{\varnothing} - x_B^{\varnothing}))$. All consumers located at $x < x_0^{\varnothing}$ purchase from firm A while the remaining consumers purchase from firm B.

The firms choose their prices $p_A^{\varnothing}$ and $p_B^{\varnothing}$ to maximize their profits, where profits are $\pi_A^{\varnothing} = x_0^{\varnothing} p_A^{\varnothing}$ and $\pi_B^{\varnothing} = (1 - x_0^{\varnothing}) p_B^{\varnothing}$. Solving the firms' profit maximization problem leads to equilibrium prices

$$p_A^{\varnothing} = \frac{t(x_B^{\varnothing} - x_A^{\varnothing})(2 + x_A^{\varnothing} + x_B^{\varnothing})}{3}, \ \ p_B^{\varnothing} = \frac{t(x_B^{\varnothing} - x_A^{\varnothing})(4 - x_A^{\varnothing} - x_B^{\varnothing})}{3},$$

with the firms' profits given by

$$\pi_A^{\varnothing} = \frac{t(x_B^{\varnothing} - x_A^{\varnothing})(2 + x_A^{\varnothing} + x_B^{\varnothing})^2}{18}, \ \ \pi_B^{\varnothing} = \frac{t(x_B^{\varnothing} - x_A^{\varnothing})(4 - x_A^{\varnothing} - x_B^{\varnothing})^2}{18}.$$

Stage 2: In the benchmark, both firms must choose uniform pricing.

Stage 1: Finally, we examine the firms' positioning decisions. The firms choose $x_A^{\varnothing}$ and $x_B^{\varnothing}$ to maximize their profits. Solving for their optimal choices, we have the following equilibrium strategies:

$$x_A^{\varnothing} = -\frac{1}{4}, \ \ x_B^{\varnothing} = \frac{5}{4}, \ \ p_A^{\varnothing} = p_B^{\varnothing} = \frac{3t}{2},$$

with profits

$$\pi_A^{\varnothing} = \pi_B^{\varnothing} = \frac{3t}{4}.$$

Consistent with the literature, when firms can adjust their positions, instead of locating themselves at the ends of the Hotelling interval, they find it optimal to differentiate themselves further to soften price competition, that is, they locate themselves outside of the interval (Tyagi 2000, Liu and Tyagi 2011, Zhang 2011). In this case, the extent of differentiation is $d^{\varnothing} = |x_B^{\varnothing} - x_A^{\varnothing}| = 3/2 > 1$, which is independent of t.

Next, we investigate the equilibrium consumer surplus (CS) and social welfare (SW) under the benchmark and summarize the results as:

$$CS^{\varnothing} = v - \frac{85t}{48}, \ \ SW^{\varnothing} = v - \frac{13t}{48}.$$

Both consumer surplus and social welfare decrease with t. Although an increase in t does not affect firm positions, it does aggravate the cost of mismatch for consumers, thereby rendering consumers and social welfare worse off.

5. Baseline PP Model Analysis

In this section, we analyze our full three-stage model and solve for the equilibrium. We first consider a special case in which PP is costless to implement (i.e., $F = 0$) and then investigate the more typical case in which PP is costly to implement.

5.1. Costless Personalized Pricing

To begin, we consider a simple case in which the cost of implementing PP is negligible and explore how the availability of PP affects differentiation, price competition, and firm profits.

Again, we work backward to find the subgame perfect equilibrium. As before, firm A is to the left of firm B, i.e., $x_A \leq x_B$. The pricing subgame involves four cases: (1) Neither firm implements PP; (2) firm A implements PP and firm B does not; (3) firm A does not implement PP and firm B implements; and (4) both firms implement PP. We solve the four cases separately in the Appendix and summarize the results in the following lemma.[3]

LEMMA 1. *When PP is costless to implement, for any firm locations $x_A \leq x_B$, both firms implement PP in equilibrium. The firms' equilibrium profits are given by*

$$\pi_A = \frac{t(x_B - x_A)(x_A + x_B)^2}{4}, \ \pi_B = \frac{t(x_B - x_A)(2 - x_A - x_B)^2}{4}.$$

When $2(5 - 3\sqrt{2})/7 < x_A + x_B < 2(2 + 3\sqrt{2})/7$, PP implementation leads to a form of prisoner's dilemma: firms' profits are lower compared to what they may have earned if they had not implemented PP and, yet, they cannot help but implement PP.

The intuition for the prisoner's dilemma is as follows. Each firm implements PP as doing so endows the firm with greater capabilities in competitive pricing. Nonetheless, when both firms implement PP, they attempt to poach each other's consumers through PP. As a result, price competition becomes intense, equilibrium prices become too low, and, the firms end up making lower profits than they would have without implementing PP.

[3] The proofs of our lemmas and propositions are in Appendix A.

Thus, we confirm that when implementing PP is costless, firms always implement PP in equilibrium. But what are the effects of PP on differentiation in equilibrium? To answer this question, we move to the first stage and solve for the firms' equilibrium positions by maximizing the firms' profits over x_A and x_B. The results are summarized in the following proposition and detailed in the Appendix.

PROPOSITION 1. *When PP is costless to implement, the firms' equilibrium positions are given by* $x_A = 1/4$, $x_B = 3/4$. *In equilibrium, both firms implement PP, and their equilibrium profits are* $\pi_A = \pi_B = t/8$.

Recall that in the uniform pricing benchmark the firms position themselves outside the Hotelling interval, that is, $x_A^{\varnothing} = -1/4 < 0$ and $x_B^{\varnothing} = 5/4 > 1$. The excessive level of differentiation softens price competition and improves firm profits. However, Proposition 1 suggests that if PP is available and costless to implement, then both firms move toward the center of the Hotelling interval, and the level of differentiation drops from $d^{\varnothing} = 3/2$ without PP to $d = x_B - x_A = 1/2$ with PP.

In addition to exacerbating price competition when firms' positions are fixed, this result shows that PP implementation further reduces differentiation when firms choose their positions endogenously. This reduction in differentiation aggravates price competition and further erodes both firms' profits. Mathematically, in a symmetric equilibrium (i.e., $x_A + x_B = 1$), the equilibrium prices are

$$(p_A, p_B) = \begin{cases} (t(1-2x)d, 0) & \text{if } x \leq \frac{1}{2}, \\ (0, t(2x-1)d) & \text{otherwise.} \end{cases}$$

Thus, as d decreases, the firms charge lower prices, which intensifies competition.

The intuition for the narrowed differentiation is as follows. Under uniform pricing, a firm always makes the same profit from every consumer it serves no matter where the consumer's taste lies. Put differently, under uniform pricing, a purchasing consumer with high misfit costs is as profitable as one with low misfit costs, provided that both consumers are covered by the firm. Under PP, however, a firm derives greater profit from a consumer with lower misfit costs than it derives from one with higher misfit costs. Therefore, when using PP, firms have stronger incentives to position themselves closer to the center of the Hotelling interval to reduce the average "distance" between themselves and their consumers. As a result, both firms narrow their differentiation, and subsequently equilibrium differentiation drops.

5.2. Costly Personalized Pricing

In this section, we consider a more general setting in which firms must incur a fixed cost $F \geq 0$ to implement PP, for example, investing in developing a database and pricing system capable of PP and/or purchasing consumer data from a third party (Matsumura and Matsushima 2015, Taylor 2004). We investigate how the PP implementation cost F affects the firms' positioning decisions and their equilibrium profits. We relegate our detailed analysis to the Appendix and present the equilibrium in Proposition 2. In our analysis we focus on the symmetric pure-strategy equilibrium in which the firm positions are symmetric around the center of the Hotelling interval, i.e., $x_A + x_B = 1$.[4] In the case of a multiplicity of equilibria, we naturally select the Pareto dominant equilibrium.

PROPOSITION 2. *Suppose that the firms must incur a fixed cost $F \geq 0$ to implement PP. The following characterizes the symmetric equilibrium:*

(i) *When $F \leq \underline{F} \approx 0.011t$, the equilibrium firm positions are $x_A = 1/4$ and $x_B = 3/4$. Both firms implement PP.*

(ii) *When $\underline{F} < F < \overline{F} \approx 0.105t$, the equilibrium firm positions are $x_A = 1/2 - 8F/t$ and $x_B = 1/2 + 8F/t$. Neither firm implements PP.*

(iii) *When $\overline{F} \leq F$, the equilibrium firm positions are $x_A = -1/4$ and $x_B = 5/4$. Neither firm implements PP.*

In Proposition 2 the equilibrium strategies are divided into three regimes. With a low F, both firms cannot help but implement PP and the resulting positions are interior solutions. With a

[4] Within certain parameter space there exist infinitely many asymmetric equilibria and none of the equilibria are Pareto-dominant. Because the firms are symmetric, it is natural to concentrate on the symmetric equilibrium outcome.

moderate F, neither firm implements PP and the resulting positions are corner solutions. In equilibrium, both firms are indifferent about whether to implement PP. With a high F, implementing PP is not a viable option. In equilibrium, neither firm implements PP, and the resulting positions are interior solutions.

Firm Positioning Proposition 2 suggests that PP implementation cost has substantial effects on firms' equilibrium positioning strategies and, hence, the extent of product differentiation. The equilibrium product differentiation is

$$d = \begin{cases} \frac{1}{2} & \text{when } F \le \underline{F}, \\ 16F/t & \text{when } \underline{F} < F < \overline{F}, \\ \frac{3}{2} & \text{when } \overline{F} \le F. \end{cases}$$

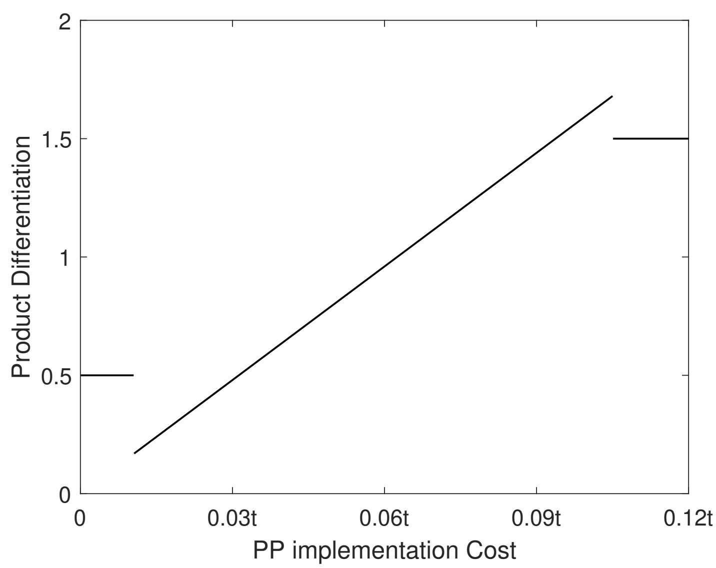

Figure 2 Implementation cost and product differentiation

Figure 2 illustrates the impact of PP implementation cost on equilibrium firm differentiation. From Figure 2, we see that the extent of differentiation is not monotone with F. The intuition is as follows. For each firm, the profitability of PP hinges on their differentiation: When the firms become more differentiated, they have a stronger incentive to implement PP. This is because with low differentiation, the firms compete more fiercely in prices with and without PP. Even though

PP can help a firm refine its pricing strategy, its profit improvement is overshadowed by fierce price competition.

In this sense, the role of differentiation is two-fold: First, a high level of differentiation directly reduces price competition, an outcome that has been well-documented in the past. Second, a high level of differentiation incentivizes firms to implement PP and, when both firms implement PP, price competition is aggravated. Firms account for both effects when making their positioning decisions. In equilibrium, they either maintain a high level of differentiation and implement PP or maintain a low level of differentiation to avoid implementing PP. Interestingly, when $3t/32 < F \leq \overline{F}$, differentiation is higher compared to what is achieved under the uniform pricing benchmark, i.e., $d = 16F/t > d^{\varnothing} = 3/2$. Put differently, the firms' abilities to implement PP *increases* differentiation.

The above discussions reveal that PP implementation costs significantly affect differentiation. New technology has significantly reduced the cost of implementing PP. For instance, the cost for data storage has fallen from \$20 per GB in 2000 to just \$2 cents per GB in 2021, while artificial intelligence technologies (e.g., facial recognition) have greatly reduced the cost of data collection and analytics. Our results indicate that a reduction in the cost of implementing PP affects not only the firms' decisions about whether to implement PP, but also their positioning decisions. When the initial PP implementation cost is moderate, reducing the cost of implementing PP reduces product differentiation. However, when the initial PP implementation cost is high or low, reducing the cost of implementing PP may also increase differentiation. As such, firms must take the above effects into consideration when making their positioning decisions.

Consumers often object to firms utilizing PP because they perceive price discrimination to be unfair, especially if they are targeted to pay higher prices than others (Li and Jain 2015). However, a recent study finds that differentiated prices are seen as unreasonable even if consumers know they are paying a lower price (i.e., they are favored by differentiation) than others (Reinartz et al. 2017). In the U.S. where privacy advocates suggest that firms are collecting too much information from people,[5] some consumer advocates are beginning to query whether government regulations should limit the use of PP to offline settings or to require its disclosure to shoppers. Our research shows that banning PP would affect not only price competition between firms, but also the firms' positioning decisions. Banning PP would increase product differentiation when the PP implementation cost is low but decrease product differentiation when the cost is moderate. Such an effect on product differentiation would have cascading effects on consumer surplus and social welfare. Public policymakers should take the above effects into consideration when deciding whether to regulate PP.

Firm Profits. Now we investigate the effect of the PP implementation cost on firms' profits. In equilibrium, the firms' profits are

$$\pi_A = \pi_B = \begin{cases} \frac{t}{8} - F & \text{when } F \leq \underline{F}, \\ 8F & \text{when } \underline{F} < F < \overline{F}, \\ \frac{3t}{4} & \text{when } \overline{F} \leq F. \end{cases}$$

The firms' profits are illustrated in Figure 3 below.

On the surface, it seems that firms can only be better off when the cost of implementing PP decreases: If a firm opts to implement PP, then a reduction in PP implementation cost saves the firm's expense and improves its profit. If a firm forgoes implementing PP, then a reduction in the cost has no effect on its profit. In either case, a firm cannot be worse off with a lower F.

Nonetheless, our results defy the above "intuition" suggesting that firms are worse off with a lower F when F is moderate. The reason is as follows. When F is moderate, neither firm implements PP, but they both must maintain low differentiation to commit to not implementing PP. As F decreases, it becomes increasingly difficult for the firms to commit to not implementing PP, and they both narrow their differentiation which intensifies price competition and hurts both firms' profit. As a result, the firms suffer from a reduction in F. These results suggest that improvements in information technology can indeed hurt firm profits as it can intensify competition.

[5] https://obamawhitehouse.archives.gov/sites/default/files/whitehouse_files/docs/Big_Data_Report_Nonembargo_v2.pdf

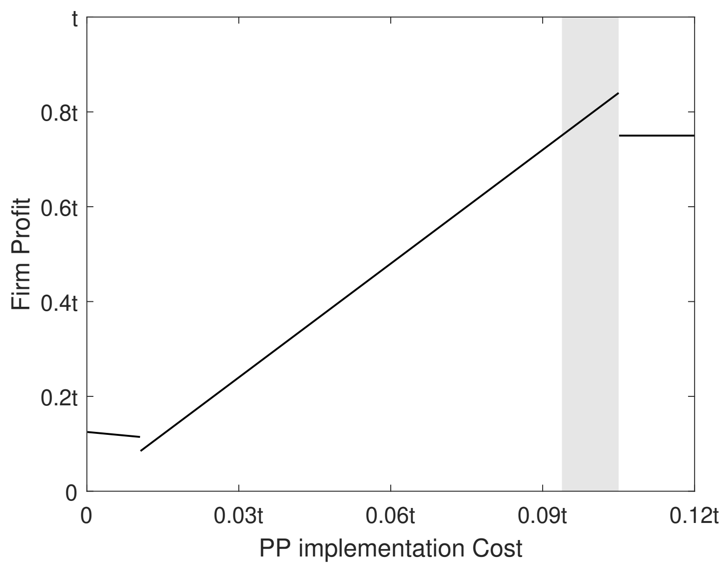

Figure 3 Implementation cost and firm profit

Next, we investigate how the firms' ability to implement PP affects their profits. We compare equilibrium firm profits under this scenario to those of the uniform pricing benchmark and summarize our results in the following proposition.

PROPOSITION 3. *If $F < 3t/32$, then firms are worse off with the ability to implement PP. If $3t/32 < F < \overline{F}$, then firms are better off with the ability to implement PP. If $\overline{F} \leq F$, then PP has no effect on the firms' profits.*

Consistent with previous findings, the first part of Proposition 3 states that when the implementation cost is low, the ability to implement PP renders both firms worse off. By contrast, the second part of Proposition 3 shows that the above findings are reversed when F is moderate. This regime is illustrated in the shaded area of Figure 3. A result that indicates both firms can be better off with the availability of PP may seem counter intuitive as well as counter to results of past studies that suggest that PP leads to a form of prisoner's dilemma. As discussed earlier, within this regime, compared to what is achieved under the uniform pricing benchmark, PP raises the level of differentiation. Accordingly, this increase in differentiation alleviates the ensuing price competition and raises firm profits. Put differently, both firms can benefit from their ability to implement PP, even though they do not actually implement PP in equilibrium.

Our results indicate that new technologies that make PP feasible may either benefit or hurt competing firms. Moreover, banning PP benefits firms when the implementation cost is low, but hurts firms when the implementation cost is moderate. As such, firms should support (oppose) a ban on PP when the implementation cost is low (moderate).

Consumer Surplus. We next consider the effects of the PP implementation cost on consumer surplus. A straightforward calculation yields consumer surplus as

$$CS = \begin{cases} v - \frac{13t}{48} & \text{when } F \leq \underline{F}, \\ v - 4F - \frac{64F^2}{t} - \frac{t}{12} & \text{when } \underline{F} < F < \overline{F}, \\ v - \frac{85t}{48} & \text{when } \overline{F} \leq F. \end{cases}$$

Figure 4 illustrates the effect of the PP implementation cost on consumer surplus.

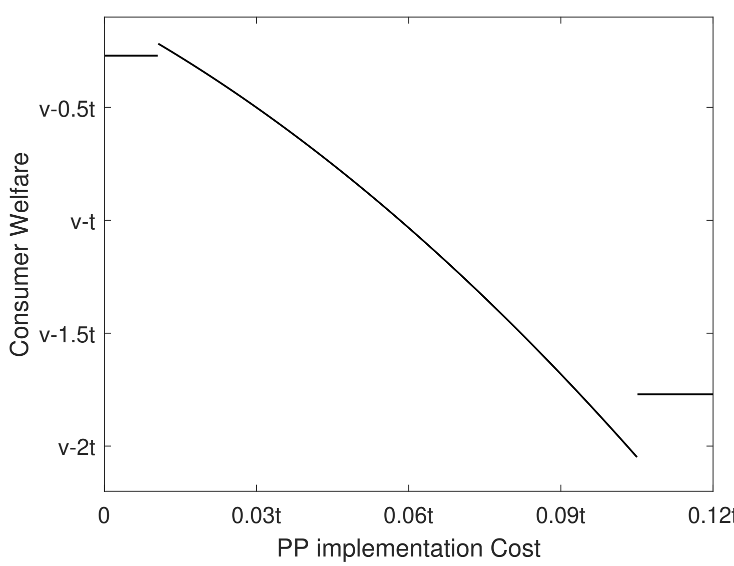

Figure 4 Implementation cost and consumer welfare

Although it seems that advances in information technology allow firms to profile individual consumers more efficiently, which should hurt individual consumers by reducing their information rent, this is not the case. The above results reveal that advances in information technology can actually benefit consumers when the PP implementation cost is moderate. This result arises because, when $\underline{F} < F < \overline{F}$, a reduction in F forces the firms to narrow their product differentiation, thereby intensifying price competition and reducing equilibrium prices which works to the benefit of consumers.

Our result also suggests that banning PP can either benefit or hurt consumers: When the PP implementation cost is low, banning PP would reduce product differentiation, intensify market competition, thereby benefiting consumers. When the implementation cost is moderate, however, banning PP would increase product differentiation, alleviate market competition, and hurt consumers. As suggested earlier, public policymakers should carefully evaluate these effects when regulating PP.

Social Welfare. Finally, we consider the effect of PP implementation cost on social welfare. Depending on whether the PP implementation cost is a deadweight loss or a fee collected by a third party, social welfare can be calculated in two ways. We adopt the interpretation that views PP implementation cost as a deadweight loss, e.g., firms invest in information infrastructures for PP. With that being said, our results are not qualitatively altered under the alternative calculation.

A straightforward calculation of equilibrium social welfare shows

$$SW = \begin{cases} v - \frac{t}{48} - 2F & \text{when } F \leq \underline{F}, \\ v + 4F - \frac{64F^2}{t} - \frac{t}{12} & \text{when } \underline{F} < F < \overline{F}, \\ v - \frac{13t}{48} & \text{when } \overline{F} \leq F. \end{cases}$$

Figure 5 illustrates the effect of PP implementation cost on social welfare. The above results suggest that, depending on the magnitude of PP implementation cost, a reduction in PP implementation cost may either improve or hurt social welfare.

Currently, public policymakers worldwide are taking measures to encourage the development and deployment of big-data technologies. For instance, in 2012, the US government announced the National Big Data Research and Development Initiative, incentivizing firms to invest in big-data technologies. The Chinese government also offers subsidies to Internet companies, encouraging them to invest in Internet technology, big data, and artificial intelligence (Leng 2017). Nonetheless, our result cautions public policymakers that advances in big-data technologies may not

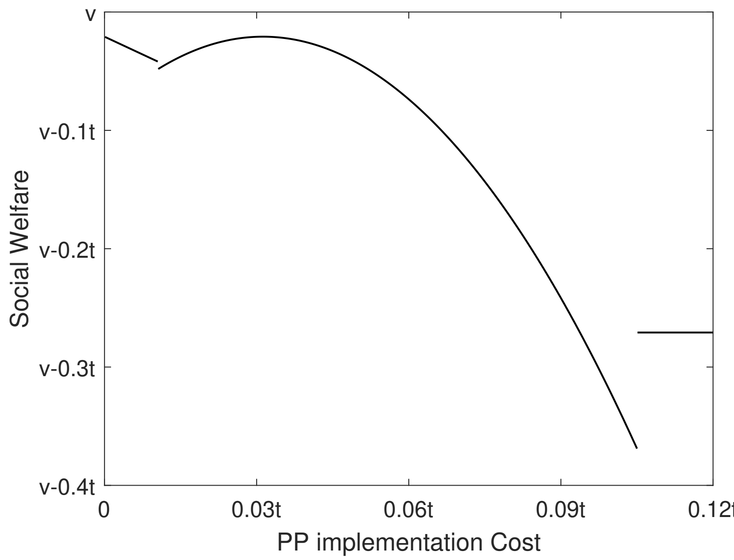

Figure 5 **Implementation cost and social welfare**

necessarily improve social welfare, and that they should carefully evaluate the potential consequences when designing policies that promote the development and implementation of big-data technology (for example, whether they should subsidize firms for adopting new information technology).

Lastly, consider the effect of banning on PP on social welfare. Like the previous results, this effect is ambiguous: banning PP would decrease social welfare when the PP implementation cost is low but increase it when the implementation cost is moderate. This informs public policymakers that they should make different decisions in regulating PP for different levels of PP implementation costs.

5.3. Information Seller

In the previous section, we assumed that PP implementation cost F was exogenously given and a deadweight loss. However, certain scenarios allow for F to be a fee chosen by a third party that, for instance, may be an information seller (e.g., Nielsen, Acxiom, and Epsilon) that owns detailed consumer information and/or has software to implement PP (Taylor 2004, Bergemann and Bonatti 2015, 2019, Huang et al. 2022). For instance, Nielsen Catalina Solutions and Oracle

Datalogix connect individual consumers with the digital media that they consume, while TowerData obtains consumers' demographic, income, intent, and purchase information through analyzing their emails. These firms all directly sell their information for profit (Bergemann and Bonatti 2019).

To model such a scenario, we modify our setup by letting an independent information seller choose the implementation cost at the beginning of our three-stage model. The information seller chooses F to maximize its profit from data and software sales.

The following proposition characterizes the information seller's optimal behavior.

PROPOSITION 4. *If an information seller controls and sets the PP implementation cost F, then it sets $F = \underline{F}$; Both firms purchase consumer information and implement PP.*

This proposition is intuitive: That is, the information seller always chooses the highest possible price at which firms are willing to implement PP. In equilibrium, the firms position themselves at $x_A = 1/4$ and $x_B = 3/4$, and social welfare is maximized (note that the implementation cost is no longer a deadweight loss). At this point, both firms engage in intense price competition, resulting in high consumer surplus (i.e., $CS \approx v - 0.27t$) but low firm profits (i.e., $\pi_A = \pi_B \approx 0.114t$).

The overall result is that both firms implement PP as in the first part of Proposition 3 whereby firms are worse off because of more intense price competition, and due to their narrowing of differentiation relative to the uniform price benchmark, the intensity of price competition is further exacerbated.

6. Short-Run Positioning Decisions

Thus far we have assumed that the firms make their positioning decisions before making their PP implementation decisions. However, in certain cases, positioning can be changed or updated relatively frequently. For example, online retailers such as Amazon and Taobao can adjust their platform designs frequently. Advertising and promotion campaigns for different offerings online can be implemented quickly, can be intense, and of short duration. These and other strategies can change consumer perceptions of firms in the short run. In contrast, the implementation of PP can take longer for firms that invest in complex information infrastructure to be able to collect and analyze consumer information gathered through payment and other systems.

In light of the above considerations, we develop an alternative model setup with short-run positioning decisions. We modify the timing of our baseline model as follows: In the first stage, two firms, A and B, simultaneously make their PP implementation decisions, denoted by $s_A, s_B \in \{\text{PP}, \emptyset\}$, with PP ($\emptyset$) denoting implementation (non-implementation). We keep our assumption that a firm must incur a fixed cost $F \geq 0$ to implement PP. If a firm does not implement PP in this stage, then it cannot do so at a later stage. In the second stage, the firms make their positioning decisions simultaneously. In the third stage, the firms set prices and compete for consumers.

We use backward induction to solve for the subgame perfect equilibrium.

Neither firm implements PP. We solve the game and find that, in equilibrium, the firms' positions are $x_A^{\emptyset} = -1/4$ and $x_B^{\emptyset} = 5/4$, where the superscript $\emptyset$ represents the case in which neither firm implements PP. Each firm charges a price $p_A^{\emptyset} = p_B^{\emptyset} = 3t/2$ and makes a profit of $\pi_A^{\emptyset} = \pi_B^{\emptyset} = 3t/4$.

Both firms implement PP. As PP implementation costs are already sunk in the first stage, they have no effect on the firms' positioning decisions. Therefore, the positioning subgame simply replicates the costless PP implementation model discussed in Section 5.1. The equilibrium firm positions are $x_A^{PP} = 1/4$ and $x_B^{PP} = 3/4$, where the superscript PP represents the case in which both firms implement PP. In equilibrium, each firm makes a profit of $\pi_A^{PP} = \pi_B^{PP} = t/8$ although this is the profit in the subgame, which does not take into account the firms' earlier investments in PP.

Only one firm implements PP. Assume without loss of generality that firm A implements PP whereas firm B does not. Again, the PP implementation cost is already sunk and does not impact the firms' positioning decisions. Let x_A^{AS} and x_B^{AS} be the firms' second stage positions, where the superscript AS represents asymmetric implementation strategies. As before let $x_A^{AS} \leq x_B^{AS}$.

In Stage 3.2, given firm B's uniform price p_B^{AS}, firm A chooses its targeted price p_A^{AS}. Simple calculation yields firm A's pricing decision as follows.

$$p_A^{AS}(x) = \begin{cases} t(x - x_B^{AS})^2 + p_B^{AS} - t(x - x_A^{AS})^2 & \text{when } x \le x_0^{AS} = \frac{x_A^{AS} + x_B^{AS}}{2} - \frac{p_B^{AS}}{2t(x_A^{AS} - x_B^{AS})}, \\ 0 & \text{when } x_0^{AS} < x. \end{cases}$$

Note that consumers with $x \le x_0^{AS}$ are covered by firm A and the rest are covered by firm B. In Stage 3.1 firm B chooses its uniform price to maximize its profit $\pi_B^{AS} = (1 - x_0^{AS})p_B^{AS}$. Maximizing firm B's profit, we find $p_B = t(x_B^{AS} - x_A^{AS})(2 - x_A^{AS} - x_B^{AS})/2$, and the firms' profits in this subgame are given by

$$\pi_A^{AS} = \frac{t(x_B^{AS} - x_A^{AS})(2 + x_A^{AS} + x_B^{AS})^2}{16}, \ \ \pi_B^{AS} = \frac{t(x_B^{AS} - x_A^{AS})(2 - x_A^{AS} - x_B^{AS})^2}{8}.$$

Next, we solve for the equilibrium positions that maximize the firms' profits in the subgame.

$$x_A^{AS} = -\frac{1}{2}, \ \ x_B^{AS} = \frac{1}{2}.$$

Interestingly, as illustrated by the equilibrium positions above, the firm that forgoes PP, firm B, is located at the center of the Hotelling interval. In contrast, the firm that implements PP, firm A, is located outside the Hotelling interval. This naturally results in firm A's position being inferior to firm B's position as consumers must incur greater misfit costs if they purchase from firm A. But, why is this so?

With implementation of PP, firm A can tailor its price offerings to different consumers, enjoying additional pricing capability in its subsequent price competition with firm B. In the second stage, firm B correctly anticipates its pricing disadvantage and aggressively moves toward the center of the Hotelling interval. By doing so, it minimizes its distance to an average consumer, which reduces consumers' misfit costs and compensates for its disadvantage in pricing. Firm B's aggressive positioning strategy forces firm A to position itself further away from the Hotelling interval to maintain reasonable differentiation and to avoid an intense price competition with firm B.

The firms' equilibrium profits in the subgame are given by $\pi_A^{AS} = \frac{t}{4}, \ \ \pi_B^{AS} = \frac{t}{2}$.

Table 1 summarizes the firms' equilibrium profits under different implementation strategies. The following proposition characterizes the equilibrium result.

Table 1 Payoff Matrix

		Firm B: PP	Firm B: U
Firm A	PP	$\left(\frac{t}{8}-F, \frac{t}{8}-F\right)$	$\left(\frac{t}{4}-F, \frac{t}{2}\right)$
	U	$\left(\frac{t}{2}, \frac{t}{4}-F\right)$	$\left(\frac{3t}{4}, \frac{3t}{4}\right)$

PROPOSITION 5. *Suppose that firms make their PP implementation decisions before making their positioning decisions. For any implementation cost $F \geq 0$, neither firm implements PP.*

Proposition 5 is in stark contrast to our previous findings, which suggest that with long-term positioning decisions, firms implement PP when the implementation cost is low.

The intuition for the above discrepancy is as follows. With long-term positioning decisions, after the positioning decisions are made, implementing PP has three effects on a firm's profit. First, PP allows a firm to offer a personalized price to individual consumers, which benefits the firm. Second, as one firm implements PP, the rival firm has to compete in prices more fiercely for consumers, which hurts the former firm. Third, firms expend a cost when implementing PP. When the PP implementation cost is low, the first effect prevails and both firms implement PP.

With short-term positioning decisions PP brings about a fourth effect: When a firm implements PP, the rival firm anticipates the former firm's enhanced pricing ability and moves toward the center of the Hotelling interval to remain competitive, an effect that hurts the former firm. This negative effect is so strong that both firms forgo implementing PP even if doing so is costless. By forgoing PP, the firms position themselves further away from each other, which mitigates competition, and they both then enjoy higher profits.

7. Model Extensions

In this section, we investigate four extensions to expand the insights from our model: (1) firms are restricted to positioning themselves within the Hotelling interval; (2) PP is not always perfect; (3) firms have different PP implementation costs; and (4) a two-period model of PP.

7.1. Firms' Positioning Space

In our Sections 5 and 6 models, we assume that firms can position themselves outside the Hotelling interval that contains consumers' ideal points, thus capturing the real-life practice of firms. For instance, when interpreting misfit as distance, firms locating their shopping malls outside the city, or firms offering products that contain nuisance features. Now, we consider a setting in which firms are restricted to locating within the Hotelling interval.

We maintain all elements of our earlier models except that we now impose the additional restriction that $0 \leq x_A, x_B \leq 1$, and investigate two cases: One with long-term positioning decisions and one with short-term positioning decisions.

As a benchmark, it is well established that when firms cannot implement PP, they choose maximum differentiation in equilibrium to soften price competition, i.e., their equilibrium positions are $(x_A^{\varnothing}, x_B^{\varnothing}) = (0,1)$ (d'Aspremont et al. 1979).

7.1.1. Long-Run Positioning Decisions Consider first a scenario in which firms make their positioning decisions before making their PP decisions. We continue to let $F \geq 0$ denote the cost of implementing PP. The analysis of the model is analogous to that of Section 5. In equilibrium, we find that, the firms' positions are

$$(x_A, x_B) = \begin{cases} \left(\frac{1}{4}, \frac{3}{4}\right) & \text{when } F \leq \underline{F}, \\ \left(\frac{1}{2} - \frac{8F}{t}, \frac{1}{2} + \frac{8F}{t}\right) & \text{when } \underline{F} < F < \frac{t}{16}, \\ (0,1) & \text{when } \frac{t}{16} \leq F. \end{cases}$$

Moreover, both firms implement PP when $F \leq \underline{F}$, and do not implement PP otherwise.

Our analysis shows that the restriction placed on firms' positioning space does not affect the equilibrium outcomes when $F \leq t/16$. Nonetheless, differentiation is now bounded above by 1, the length of the Hotelling interval, and, therefore, the level of differentiation ceases to grow after reaching $d = 1$ at $F = t/16$, a result that contrasts the findings of our baseline model. More importantly, in our baseline model, we find that when the PP implementation cost is moderate, the firms' ability to implement PP can increase product differentiation and improve firm profits.

The above result, however, does not hold in the current setting. This suggests that the profitability of PP hinges critically on the firms' positioning space, and that when the firms' positioning space is restricted, banning PP will always increase market competition and benefit consumers.

Note that the restriction placed on the firms' positioning space is more a mathematical assumption than a reflection of reality. As Liu and Tyagi state: *"restricting firms to a position within the unit interval in this modeling framework would mask those additional economic incentives to differentiate"* (2011, p.748).

7.1.2. Short-Run Positioning Decisions The analysis of our earlier models suggests that the timing of the firms' decisions has substantial effects on the equilibrium. When the firms make their PP implementation decisions before making their positioning decisions, both firms forfeit PP even if it is costless to implement. One may then wonder whether this insight continues to hold when the firms' positioning space is restricted.

The solution is analogous to that of Section 6. When both firms implement PP, their equilibrium positions are given by $x_A^{PP} = 1/4$ and $x_B^{PP} = 3/4$, with each firm making a profit of $t/8 - F$. When neither firm implements PP, their equilibrium positions are given by $x_A^{\varnothing} = 0$ and $x_B^{\varnothing} = 1$, that is, the firms prefer maximal differentiation. Finally, consider the subgame in which firm A implements PP and firm B does not. We solve for the firms' equilibrium strategies and obtain their equilibrium positions:

$$x_A^{AS} = 0, \;\; x_B^{AS} = \frac{2}{3}.$$

When the firms' positioning space is restricted, firm B still gains an advantageous position that is, on average, "closer" to consumers whereas firm A's position is not.

Following this analysis, Table 2 summarizes the firms' payoffs under different implementation strategies. For any $F \geq 0$, a unique equilibrium exists in which neither firm implements PP, thereby replicating the findings regarding implementing PP of our model in Section 6.

Table 2 Payoff Matrix

		Firm B	
		PP	U
Firm A	PP	$\left(\frac{t}{8}-F, \frac{t}{8}-F\right)$	$\left(\frac{8t}{27}-F, \frac{4t}{27}\right)$
	U	$\left(\frac{4t}{27}, \frac{8t}{27}-F\right)$	$\left(\frac{t}{2}, \frac{t}{2}\right)$

7.2. Imperfect Price Discrimination

In Sections 5 and 6, we assume that once a firm implements PP, it recognizes and targets all consumers perfectly. In practice, the firm may not be able to identify all consumers individually because of limited data, imperfect algorithms, or consumers' information hiding behavior.

To capture the above issue, we formulate a setting in which the firms cannot identify all consumers. We assume that by implementing PP, each firm can identify a faction α of the consumers but cannot identify the remaining consumers. Moreover, the identified consumers are the same for both firms because, for instance, both firms purchase consumer data from the same data vendor, or they adopt the same data collection technology. If a firm implements PP, then it offers a personalized price to each identifiable consumer but offers a uniform price to those it cannot identify. If a firm does not implement PP, then it offers a uniform price to all consumers. We maintain the other assumptions of our models in earlier sections. We focus on the case in which both firms make long-term positioning decisions.

Given the firms' locations x_A and x_B and their PP implementation decision, we solve the four pricing subgames and summarize the equilibrium outcome in the following lemma:

LEMMA 2. *Suppose that the firms' targeting technology is imperfect. Given the firms' locations x_A and x_B and their PP implementation decision, the firm profits are as follows.*

- *If both firms implement PP, then the firms' profits are*

$$\pi_A = \frac{\alpha(x_B - x_A)(2 + x_A + x_B)^2 t}{18} + \frac{(1-\alpha)(x_B - x_A)(x_A + x_B)^2 t}{4} - F,$$

$$\pi_B = \frac{\alpha(x_B - x_A)(4 - x_A - x_B)^2 t}{18} + \frac{(1-\alpha)(x_B - x_A)(2 - x_A - x_B)^2 t}{4} - F.$$

- *If only firm B implements PP, then the firms' profits are*

$$\pi_A = \frac{(x_B - x_A)(2 + x_A + x_B - (2 - x_A - x_B)\alpha)^2 t}{2(3+\alpha)^2},$$

$$\pi_B = \frac{(x_B - x_A)(4 - x_A - x_B)^2(1+\alpha)t}{2(3+\alpha)^2} - F.$$

- *If neither firm implements PP, then the firms' profits are*

$$\pi_A = \frac{(x_B - x_A)(2 + x_A + x_B)^2 t}{18}, \ \pi_B = \frac{(x_B - x_A)(4 - x_A - x_B)^2 t}{18}.$$

Next, we consider the firms' positioning and PP implementation decisions. Due to the complexity of the model, we are not able to characterize the equilibrium for general values of F and α. We consider two forms of the relationship between F and α: F is linear in α and is quadratic in α. Although we relegate our detailed analysis to Appendix B, the general intuition is as follows. When α is low, given the low implementation cost, both firms always implement PP, and the equilibrium is an interior solution. When α is moderate, both firms choose their locations to avoid implementing PP, and the equilibrium is a corner solution. In equilibrium, both firms are indifferent about implementing PP or not. Lastly, when α is high, the firms never implement PP, and the resulting equilibrium is, again, an interior solution.

7.3. Asymmetric Implementation Costs

In our Sections 5 and 6 models, we assume that both firms share the same PP implementation cost F; for example, they purchase consumer data from the same data vendor at the same price. It is also possible that firms differ in their technological capabilities and have different implementation costs. To capture this possibility, we extend our model to consider a scenario in which the firms' PP implementation costs differ.

We assume, for the sake of tractability, that firm A's PP implementation cost is $F \geq 0$ while firm B does not incur any costs implementing PP. We assume that the firms first make their positioning decisions and then make their PP implementation decisions. We solve for the equilibrium and summarize the results in the following proposition. Without loss of generality, we focus on the equilibrium in which $x_A \leq x_B$.

PROPOSITION 6. *Suppose that firm A's PP implementation cost is F whereas firm B does not incur any costs implementing PP. In equilibrium, the firms' positioning decisions are as follows:*

$$(x_A, x_B) = \begin{cases} \left(\frac{1}{4}, \frac{3}{4}\right) & \text{when } F \leq F_1 \approx 0.01054t, \\ \text{no pure strategy equilibrium} & \text{when } F_1 < F < \frac{t}{54}, \\ \left(\sqrt[3]{\frac{F}{4t}}, 3\sqrt[3]{\frac{F}{4t}}\right) & \text{when } \frac{t}{54} \leq F \leq \frac{t}{2}, \\ \left(\frac{1}{2}, \frac{3}{2}\right) & \text{when } \frac{t}{2} \leq F. \end{cases}$$

When $F \leq F_1$, both firms implement PP and when $\frac{t}{54} \leq F$, only firm B implements PP.

The intuition for Proposition 6 is as follows. When $F \leq F_1$, firm A's PP implementation cost is low enough and it always implements PP. Similarly, firm B implements PP as well. As such, both firms always implement PP, and the resulting equilibrium is $\left(\frac{1}{4}, \frac{3}{4}\right)$, an interior solution.

As F increases past F_1, $\left(\frac{1}{4}, \frac{3}{4}\right)$ is no longer an equilibrium. The intuition is as follows. If firm A still chooses $x_A = \frac{1}{4}$, then firm B has an incentive to deviate and move to some $x_B < \frac{3}{4}$, which forces firm A to give up implementing PP, thereby improving firm B's profit. Indeed, in this case we find that there is no pure-strategy equilibrium.

When $\frac{t}{54} \leq F \leq \frac{t}{2}$, firm A's PP implementation cost is high. At the specified equilibrium $\left(\sqrt[3]{\frac{F}{4t}}, 3\sqrt[3]{\frac{F}{4t}}\right)$, firm B implements PP whereas firm A is indifferent about implementing PP or not and we assume that it forgoes PP (which is Pareto-dominant). As such, the equilibrium is a corner solution.

Finally, when $\frac{t}{2} \leq F$, implementing PP is no longer a viable option for firm A and the resulting equilibrium is an interior solution. In this equilibrium, only firm B implements PP.

It is worth noting that, in the above model, the firms' ability to implement PP does not increase their product differentiation or improve firm profits, a result that contrasts that of our baseline model. The reason is as follows. In our baseline model, when the PP implementation cost is moderate, firms choose their locations carefully to commit to not implementing PP. In the current model, however, firm B always implements PP given the zero implementation cost, and the above reasoning disappears. As such, the firms cannot benefit from their ability to implement PP.

Our analysis shows the significant effects that asymmetric implementation costs have on firms' positioning decisions. Interestingly, the analysis suggests that the firm with high PP implementation costs often ends up with a superior location (i.e., a location that is closer to the center of the Hotelling interval) and making higher profits. In line with our analysis in Section 6, the firm with a higher PP implementation cost, anticipating that it will have a disadvantage in the subsequent pricing subgame, becomes more aggressive in making its positioning decisions, thereby translating its pricing disadvantage into its positioning advantage. Again, our results show reductions in PP implementation costs do not necessarily benefit firms.

7.4. A Two-Period Model of PP

Our baseline model assumes that the firms are endowed with consumers' preference data (e.g., the firms purchased data from an information seller) and can offer each consumer a customized price. In practice, it is also plausible that the firms collect data from consumers over time. To capture this scenario, in this section we consider a two-period model of PP, in which the firms learn about consumer preference in the first period and use the data to price discriminate against consumers in the second period.

The timeline of the model is as follows. The first period consists of three stages. In the first stage, the firms choose their locations, x_A and x_B. In the second stage, the firms decide whether or not to invest in PP at an investment cost $F \geq 0$. In the third stage, the firms charge first-period prices p_{A1} and p_{A2} to consumers. Note that because firms do not have any data in the first period, they both offer a uniform price to consumers. The second period consists of two stages. In the first stage, if firm j did not implement PP, it charges a uniform price p_{j2} to consumers. In the second stage, if firm j implements PP, it charges a customized price $p_{j2}(x)$ to consumer located at x. For simplicity, we assume that neither the firms nor consumers discount their future payoffs.

We solve for the firms' location decision and summarize the results as follows.

$$(x_A, x_B) = \begin{cases} \left(\frac{1}{20}, \frac{19}{20}\right) & \text{when } F \leq \underline{F} \approx 0.0216t, \\ \left(\frac{1}{2} - \frac{8F}{t}, \frac{1}{2} + \frac{8F}{t}\right) & \text{when } \underline{F} < F < \overline{F} \approx 0.105t, \\ \left(-\frac{1}{4}, \frac{5}{4}\right) & \text{when } \overline{F} \leq F. \end{cases}$$

We can show that our main intuitions from our models in earlier sections continue to hold under the two-stage model setup. For instance, Figure 6 characterizes how the equilibrium product differentiation changes with the PP implementation cost. Like in our baseline model, in the two-stage model, when F is low, both firms always implement PP and product differentiation is a constant. When F is moderate, both firms choose their locations carefully to avoid implementing PP; in equilibrium, the firms are indifferent about whether to implement PP. As F increases, it is easier for the firms to commit to forfeiting PP, and product differentiation increases. Finally, when F is large enough, implementing PP is no longer a viable option for the firms, and the resulting locations are interior solutions. Within this parameter space, product differentiation is, once again, constant with F.

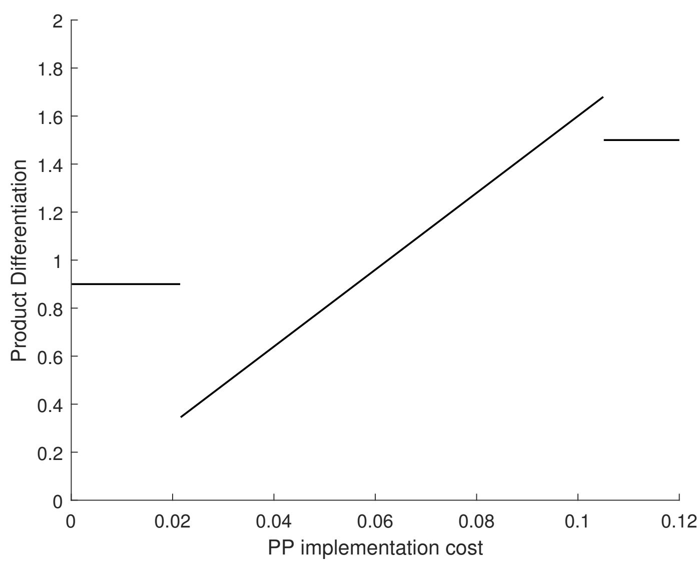

Figure 6 Implementation cost and product differentiation (two-stage model)

It is also worth mentioning that when F is moderate, compared to the uniform pricing benchmark, the firms' ability to implement PP again increases product differentiation, alleviates product competition and benefits both firms, thereby replicating the result of our baseline model.

8. Conclusion

Modern information technology imbues firms with increasingly intricate and reliable ways to collect consumer data and use it for PP. The ability to implement PP affects a variety of decisions that firms make including their strategic positioning that affects differentiation. We examine competitive positioning strategies that firms may employ when they have the option to implement PP. We compare that equilibrium with the equilibrium in which PP is not feasible (i.e., firms can only use uniform pricing). This allows us to directly observe the effects of PP on firm profits, consumer surplus, and social welfare.

When firms make their positioning decisions before making their PP decisions and the cost to implement PP is low, they cannot help but implement PP and, as a result, become more flexible in setting prices; however, this collective decision intensifies the price competition and lowers firm profits. Although such peril has been well documented in the literature, we excavate another danger of PP. Under PP, our two firms position themselves toward the center of the Hotelling line, which narrows their differentiation and further intensifies price competition. As a result, both firms suffer from a substantial profit loss even when they can implement PP at a low cost.

When PP implementation cost is moderate, the firms can forfeit PP; however, they must narrow their differentiation significantly to commit to this forfeiting decision. Even though the firms do not implement PP in equilibrium, such a reduction in differentiation intensifies price competition and renders both firms worse off. As the cost of implementing PP increases, firms can more easily commit to forgoing PP, and differentiation increases as do corresponding firm profits. Interestingly, when the cost of implementing PP is high but not prohibitively so, firms choose to become more differentiated as compared to what they are under uniform pricing, and they benefit from their ability to implement PP. This result is in stark contrast to the prisoner's dilemma, an outcome staunchly advanced by previous literature. Of course, when the implementation cost is high enough, implementing PP is not viable for firms and PP has no effect on the equilibrium.

We also find that settings in which firms make their PP implementation decisions before making their positioning decisions – that is, scenarios where PP implementation is complex and positioning can be changed in the short-run – firms never implement PP even if it is costless to do so. The rationale behind this dictates that, when one firm implements PP, its profits are eroded by the rival firm's aggressive positioning response. As a result, neither firm implements PP in equilibrium, and both firms escape the PP-induced prisoner's dilemma.

The key limitation of our work is the degree to which our model is stylized with two firms and specific function form choices. This modeling approach shows what can happen, and the generalizability of the results from our approach depends on how reasonable the setup and functional form choices are. Our use of commonly-used forms is a step in the direction of generalizability, and we believe that the tradeoffs we found between the advantages of price targeting with PP and the intensity of price competition that results from differentiation apply broadly.

Our research can be extended in a number of directions. In our model, PP only affects consumers through prices and firm positioning. Consumers may object to PP for other reasons such as privacy and fairness concerns. Although not formally modeling privacy or fairness, our result that banning PP can benefit consumers – which contrasts with prior work – is a step in this direction. Conversely, firms equipped with consumers' personal information may better serve consumers with personalized services and product recommendations for which consumers may be open to PP (Acquisti and Varian 2005). With these benefits, firms, in turn, may be more willing to implement PP. Modeling and examining the implications of such considerations on the equilibrium strategies may yield further insights into PP.

Our model also assumes that once a firm has information about a consumer, its information is perfect. Nonetheless, firms' targeting technologies are not always perfect and, at times, an algorithm may make inaccurate predictions about consumers' preferences. Although we have taken a step in this direction in some of our model extensions in Section 7, future work may consider our setup with more elaborate modeling of imperfect targeting technologies.

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Appendix A: Technical Details

Proof of Lemma 1. To prove the lemma, we consider different cases of PP implementation decisions given the firm positions x_A, x_B (assuming that $x_A \leq x_B$).

First, suppose that both firms implement PP. Consider a consumer located at $x \in [0,1]$. The consumers' valuation for good or service A is $v_A = v - t(x-x_A)^2$, and their valuation for good or service B is $v_B = v - t(x-x_B)^2$. Note that $v_A > v_B$ if and only if $x < x_0 = \frac{x_A+x_B}{2}$. As both firms know the consumer's "location" x, they compete à la Bertrand for that consumer. The resulting prices are

$$(p_A(x), p_B(x)) = \begin{cases} (t(x-x_B)^2 - t(x-x_A)^2, 0) & \text{when } x \leq x_0, \\ (0, t(x-x_A)^2 - t(x-x_B)^2) & \text{when } x_0 < x. \end{cases}$$

All consumers located between 0 and x_0 purchase from firm A and all consumers located between x_0 and 1 purchase from firm B. It follows that the firms' profits are

$$\pi_A = \int_0^{x_0} p_A(x)dx = \frac{t(x_B-x_A)(x_A+x_B)^2}{4},$$
$$\pi_B = \int_{x_0}^{1} p_B(x)dx = \frac{t(x_B-x_A)(2-x_A-x_B)^2}{4}.$$

Now consider the asymmetric case where only one firm implements PP. Assume without loss of generality it is firm B. In the game, firm A firm chooses a uniform price p_A for all its consumers, and then firm B choose its customized price $p_B(x)$ for each consumer $x \in [0,1]$. A consumer at x purchases from firm B if and only if

$$v - p_B(x) - t(x-x_B)^2 \geq v - p_A - t(x-x_A)^2,$$

or $p_B(x) \leq p_A + t(x-x_A)^2 - t(x-x_B)^2$. Then firm B's optimal pricing strategy is

$$p_B(x) = \begin{cases} 0 & \text{when } x \leq x_0, \\ p_A + t(x-x_A)^2 - t(x-x_B)^2 & \text{when } x_0 < x. \end{cases}$$

where $x_0 = \frac{p_A + tx_A^2 - tx_B^2}{2t(x_A-x_B)}$. Firm A's profit is $p_A x_0$. Solving firm A's profit maximization problem we obtain

$$p_A = \frac{t(x_A+x_B)(x_B-x_A)}{2}.$$

In equilibrium, the firms' profits are

$$\pi_A = \frac{t(x_B-x_A)(x_A+x_B)^2}{8}, \quad \pi_B = \frac{t(x_B-x_A)(4-x_A-x_B)^2}{16}.$$

Table 3 Payoff Matrix

		Firm B: PP	Firm B: U
Firm A	PP	$\left(\frac{t(x_B-x_A)(x_A+x_B)^2}{4}, \frac{t(x_B-x_A)(2-x_A-x_B)^2}{4}\right)$	$\left(\frac{t(x_B-x_A)(2+x_A+x_B)^2}{16}, \frac{t(x_B-x_A)(2-x_A-x_B)^2}{8}\right)$
	U	$\left(\frac{t(x_B-x_A)(x_A+x_B)^2}{8}, \frac{t(x_B-x_A)(4-x_A-x_B)^2}{16}\right)$	$\left(\frac{t(x_B-x_A)(2+x_A+x_B)^2}{18}, \frac{t(x_B-x_A)(4-x_A-x_B)^2}{18}\right)$

Symmetrically, when firm A implements PP whereas firm B does not, the equilibrium firm profits are

$$\pi_A = \frac{t(x_B - x_A)(2 + x_A + x_B)^2}{16}, \quad \pi_B = \frac{t(x_B - x_A)(2 - x_A - x_B)^2}{8}.$$

Finally, the case where neither firm implements PP is straightforward to analyze and is omitted. The firms' payoff matrix is summarized in Table 3. By comparing the firms' profits in different cases, Lemma 1 follows immediately. Q.E.D.

Proof of Proposition 1. Following the proof of Lemma 1, the firms' equilibrium profits are

$$\pi_A = \frac{t(x_B - x_A)(x_A + x_B)^2}{4}, \ \pi_B = \frac{t(x_B - x_A)(2 - x_A - x_B)^2}{4}.$$

Maximizing π_A over x_A and π_B over x_B proves the proposition. Q.E.D.

Proof of Proposition 2. Consider first case (1): $F \le 0.0105t$. If both firms follow the equilibrium positioning strategies, then their positions are $x_A = \frac{1}{4}$, $x_B = \frac{3}{4}$ and profits are $\pi_A = \pi_B = \frac{t}{8} - F$. Now consider the firms' incentive to deviate. Assume without loss of generality that firm A deviates. Consider the following cases.

Case (1.1). Firm A chooses a different position $x_A < \frac{1}{4}$. Simple algebra shows that whenever $x_A < \frac{1}{4}, x_B = \frac{3}{4}$, firm B always implements PP. Firm A's deviation profit, π'_A, is thus bounded above by

$$\pi'_A \le \max\left(\frac{t(x_B - x_A)(x_A + x_B)^2}{4} - F, \frac{t(x_B - x_A)(x_A + x_B)^2}{8}\right)$$

subject to $x_A + x_B > 0$ (It can be verified that when $x_A + x_B \le 0$, firm A has zero market share and makes zero profit). Straightforward calculation shows that $\pi'_A \le \frac{t}{8} - F$, and thus it does not have any incentive to deviate.

Case (1.2). Firm A chooses a different position $\frac{1}{4} < x_A \le \frac{3}{4}$. In this case, firm A's deviation profit is bounded above by $\pi'_A \le \max(A_1, A_2)$ where

$$A_1 = \begin{cases} \frac{t(x_B-x_A)(2+x_A+x_B)^2}{16} - F & \text{if } \frac{t(x_B-x_A)(2-x_A-x_B)^2}{8} \ge \frac{t(x_B-x_A)(2-x_A-x_B)^2}{4} - F, \\ \frac{t(x_B-x_A)(x_A+x_B)^2}{4} - F & \text{otherwise.} \end{cases}$$

$$A_2 = \begin{cases} \frac{t(x_B-x_A)(2+x_A+x_B)^2}{18} & \text{if } \frac{t(x_B-x_A)(4-x_A-x_B)^2}{18} \geq \frac{t(x_B-x_A)(4-x_A-x_B)^2}{16} - F, \\ \frac{t(x_B-x_A)(x_A+x_B)^2}{8} & \text{otherwise.} \end{cases}$$

We can verify that $\pi'_A \leq \max(A_1, A_2) \leq \frac{t}{8} - F$ and firm A has no incentive to deviate.

Case (1.3). Firm A chooses a different position $x_A > x_B = \frac{3}{4}$. In this case, firm A is positioned on the right hand side of firm B. Its deviation profit is bounded above by $\pi'_A \leq \max(A_3, A_4)$ where

$$A_3 = \begin{cases} \frac{t(x_A-x_B)(4-x_A-x_B)^2}{16} - F & \text{if } \frac{t(x_A-x_B)(x_A+x_B)^2}{8} \geq \frac{t(x_A-x_B)(x_A+x_B)^2}{4} - F, \\ \frac{t(x_A-x_B)(2-x_A-x_B)^2}{4} - F & \text{otherwise.} \end{cases}$$

$$A_4 = \begin{cases} \frac{t(x_A-x_B)(4-x_A-x_B)^2}{18} & \text{if } \frac{t(x_A-x_B)(2+x_A+x_B)^2}{18} \geq \frac{t(x_A-x_B)(2+x_A+x_B)^2}{16} - F, \\ \frac{t(x_A-x_B)(2-x_A-x_B)^2}{8} & \text{otherwise.} \end{cases}$$

We can verify that $\pi'_A \leq \max(A_3, A_4) \leq \frac{t}{8} - F$ and firm A has no incentive to deviate.

Next consider case (2): $0.0105t < F \leq \frac{3t}{32}$. We first show that $x_A = 1/4$ and $x_B = 3/4$ do not constitute an equilibrium. To see this, assume for contradiction that there exists such an equilibrium. If firm A does not deviate, then it makes equilibrium profit of $\pi^*_A = t/8 - F$. Now consider the following deviation by firm A: instead of choosing $x_A = 1/4$, firm A chooses a new position x_A which is implicitly given by

$$\frac{t}{8}\left(\frac{3}{4} - x_A\right)\left(\frac{5}{4} - x_A\right)^2 = F.$$

It can be shown that given the new position x_A and $x_B = 3/4$, in equilibrium, firm A implements PP whereas firm B does not. Firm A's deviating profit is higher than $\pi^*_A = t/8 - F$. Therefore, the proposed equilibrium is not sustained.

Next we show that $x_A = 1/2 - 8F/t$ and $x_B = 1/2 + 8F/t$ constitute an equilibrium. If both firms follow their equilibrium strategies, then neither firm implements PP and each makes a profit $\pi_A = \pi_B = 8F$. To prove this is an equilibrium, we consider firm A's incentive to deviate. Again, there are three subcases as follows.

Case (2.1). $x_A < \frac{1}{2} - \frac{8F}{t}$. It is easy to verify that in this case firm B always implements PP. Firm A's deviation profit, π'_A, is thus bounded above by

$$\pi'_A \leq \max\left(\frac{t(x_B - x_A)(x_A + x_B)^2}{4} - F, \frac{t(x_B - x_A)(x_A + x_B)^2}{8}\right)$$

subject to $x_A + x_B > 0$ (If $x_A + x_B \leq 0$, firm A has zero market share). Straightforward calculation shows that $\pi'_A \leq 8F$, and thus it does not have an incentive to deviate.

Case (2.2). $\frac{1}{2} - \frac{8F}{t} < x_A \le \frac{1}{2} + \frac{8F}{t}$. Straightforward calculation suggests that neither firm implements PP and firm A's deviation profit is

$$\pi'_A = \frac{t(x_B - x_A)(2 + x_A + x_B)^2}{18},$$

which is deceasing in x_A when $\frac{1}{2} - \frac{8F}{t} < x_A \le \frac{1}{2} + \frac{8F}{t}$. Therefore, firm A does not have an incentive to deviate.

Case (2.3). $x_B = \frac{1}{2} + \frac{8F}{t} < x_A$. Like case (1.3), firm A is positioned on the right hand side of firm B. Its deviation profit is bounded above by $\pi'_A \le \max(A_3, A_4)$ where

$$A_3 = \begin{cases} \frac{t(x_A - x_B)(4 - x_A - x_B)^2}{16} - F & \text{if } \frac{t(x_A - x_B)(x_A + x_B)^2}{8} \ge \frac{t(x_A - x_B)(x_A + x_B)^2}{4} - F, \\ \frac{t(x_A - x_B)(2 - x_A - x_B)^2}{4} - F & \text{otherwise.} \end{cases}$$

$$A_4 = \begin{cases} \frac{t(x_A - x_B)(4 - x_A - x_B)^2}{18} & \text{if } \frac{t(x_A - x_B)(2 + x_A + x_B)^2}{18} \ge \frac{t(x_A - x_B)(2 + x_A + x_B)^2}{16} - F, \\ \frac{t(x_A - x_B)(2 - x_A - x_B)^2}{8} & \text{otherwise.} \end{cases}$$

We can verify that $\pi'_A \le \max(A_3, A_4) \le 8F$ and firm A does not have an incentive to deviate.

Now consider case (3): $\frac{3t}{32} < F \le 0.105t$. If both firms follow their equilibrium strategies, then neither firm implements PP and each of them makes a profit $\pi_A = \pi_B = 8F$. To prove this is an equilibrium, we consider firm A's incentive to deviate. Again, consider the following three subcases.

Case (3.1). $x_A < \frac{1}{2} - \frac{8F}{t}$. It is easy to verify that in this case firm B always implements PP. The analysis is similar to case (2.1) and is omitted.

Case (3.2). $\frac{1}{2} - \frac{8F}{t} < x_A \le \frac{1}{2} + \frac{8F}{t}$. Calculation shows that firm A's deviation profit, π'_A, is

$$\pi'_A = \begin{cases} \frac{t(x_A - x_B)(x_A + x_B)^2}{4} - F & \text{if } \frac{t(x_A - x_B)(x_A + x_B)^2}{8} < \frac{t(x_A - x_B)(x_A + x_B)^2}{4} - F, \\ \frac{t(x_A - x_B)(2 + x_A + x_B)^2}{18} & \text{otherwise.} \end{cases}$$

We then verify that $\pi'_A \le 8F$, and firm A has no incentive to deviate.

Case (3.3). This case is similar to case (2.3) and is omitted.

Finally, consider case (4): $0.105t < F$. If both firms follow their equilibrium positioning strategies (i.e., $x_A = -\frac{1}{4}$ and $x_B = \frac{5}{4}$), then neither firm implements PP and each of them makes a profit $\pi_A = \pi_B = \frac{3t}{4}$. Again, consider firm A's incentive to deviate.

Case (4.1). x_A is so small such that $t(x_B - x_A)(4 - x_A - x_B)^2 > 144F$. In this case, firm B always implements PP, and firm A's deviation profit, π'_A, satisfies

$$\pi'_A \le \max\left(\frac{t(x_B - x_A)(x_A + x_B)^2}{4} - F, \frac{t(x_B - x_A)(x_A + x_B)^2}{8}\right) < \frac{3t}{4}.$$

Therefore firm A has no incentive to deviate.

Case (4.2). $x_A \le x_B$ and $t(x_B - x_A)(4 - x_A - x_B)^2 \le 144F$. In this case, neither firm implements PP, and firm A' deviation profit is

$$\pi'_A = \frac{t(x_B - x_A)(2 + x_A + x_B)^2}{18},$$

which is maximized when $x_A = -\frac{1}{4}$. As such, firm A has no incentive to deviate.

Case (4.3). $x_A > x_B$. The analysis is similar to cases (1.3) and (2.3). Firm A does not have an incentive to deviate either.

This completes the proof. Q.E.D.

Proof of Proposition 3. First, when $F \le \underline{F}$, we have $\pi_A = \pi_B = \frac{t}{8} - F < \frac{3t}{4}$. Second, when $\underline{F} < F < \frac{3t}{32}$, we have $\pi_A = \pi_B = 8F < \frac{3t}{4}$. Third, when $\frac{3t}{32} < F < \bar{F}$, we have $\pi_A = \pi_B = 8F > \frac{3t}{4}$. Fourth, when $\bar{F} \le F$, we have $\pi_A = \pi_B = \frac{3t}{4}$. Therefore, the firms' ability to implement PP hurts their profits when $F < \frac{3t}{32}$, improves their profits when $\frac{3t}{32} < F < \bar{F}$, and has effects on their profits when $\bar{F} \le F$. Q.E.D.

Proof of Proposition 4. Note first that an information seller will never choose a fee $F > \bar{F}$; otherwise, neither firm will implement PP and the information seller's profit will be 0. When the information seller charges a fee $F \le \underline{F}$, both firms always implement PP, and the information seller's profit increases with F. As a result, the information seller chooses $F = \underline{F}$ in equilibrium. Q.E.D.

Proof of Proposition 5. The proposition follows immediately from Table 1. Q.E.D.

Proof of Lemma 2. (1) If both firms implement PP, they compete separately for identifiable and unidentifiable consumers. Following the proof of Lemma 1, the firms' expected profits from an identifiable consumer are

$$\pi_{AI} = \frac{t(x_B - x_A)(2 + x_A + x_B)^2}{18}, \ \pi_{BI} = \frac{t(x_B - x_A)(4 - x_A - x_B)^2}{18}.$$

The firms' expected profits from an unidentifiable consumer are

$$\pi_{AU} = \frac{t(x_B - x_A)(x_A + x_B)^2}{4}, \ \pi_{BU} = \frac{t(x_B - x_A)(2 - x_A - x_B)^2}{4}.$$

The firms' total profits are given by $\pi_A = \alpha\pi_{AI} + (1-\alpha)\pi_{AU} - F$ and $\pi_B = \alpha\pi_{BI} + (1-\alpha)\pi_{BU} - F$, which are summarized in Lemma 2.

(2) Consider the case in which only one firm implements PP; assume without loss of generality that firm B implements PP. We now derive the firms' pricing decision. Given p_A, for identifiable consumers located at x, firm B charges a price

$$p_B(x) = \begin{cases} 0 & \text{when } x \leq x_{0I}, \\ p_A + t(x - x_A)^2 - t(x - x_B)^2 & \text{when } x_0 < x. \end{cases}$$

where $x_{0I} = \frac{p_A + tx_A^2 - tx_B^2}{2t(x_A - x_B)}$. For unidentifiable consumers, firm B charges a uniform price p_B, and the indifferent consumer is located at $x_{0U} = \frac{p_B - p_A + t(x_B^2 - x_A^2)}{2t(x_B - x_A)}$. The firms' profits are given by

$$\pi_A = \alpha p_A x_{0I} + (1 - \alpha) p_A x_{0U},$$

$$\pi_B = \alpha \int_{x_{0I}}^{1} p_B(x) dx + (1 - \alpha) p_B (1 - x_{0U}) - F.$$

Maximizing π_A and π_B, we derive the firms' uniform prices as follows:

$$p_A = \frac{t(x_B - x_A)(2 + x_A + x_B - (2 - x_A - x_B)\alpha)}{3 + \alpha}, \ p_B = \frac{t(x_B - x_A)(4 - x_A - x_B)}{3 + \alpha}.$$

The firms' profits are summarized in Lemma 2.

(3) When neither firm implements PP, then the equilibrium outcome replicates the uniform pricing benchmark, and the firms' profits are summarized in Lemma 2. Q.E.D.

Proof of Proposition 6. Because firm B's PP implementation cost is zero, it always implements PP. Depending on the magnitude of the PP implementation cost, firm A may and may not implement PP in equilibrium. We consider the following possible equilibria.

Case (1) The equilibrium firm locations are interior solutions.

Case (1.1): Firm A implements PP. It follows immediately that when both firms implement PP, the interior solutions to firm locations are $x_A = \frac{1}{4}$ and $x_B = \frac{3}{4}$. It is easy to verify that this is indeed an equilibrium as long as $F \leq F_1$. When $F > F_1$, however, the above equilibrium no longer exists. Consider the following deviation by firm B: Instead of choosing $x_B = \frac{3}{4}$, it deviates and chooses an x_B such that $\frac{(x_B - x_A)(x_A + x_B)^2}{8} = \frac{F}{t}$. Given x_B, firm A will forgo PP, resulting in higher profits for firm B.

Case (1.2): Firm A does not implement PP. It follows immediately that when firm A does not implement PP whereas firm B implements, the interior solutions to firm locations are $x_A = \frac{1}{2}$ and $x_B = \frac{3}{2}$. It is easy to verify that this is an equilibrium outcome when $F \geq \frac{t}{2}$. When $F < \frac{t}{2}$, however, firm A is better off deviating and implementing PP, and the assumed equilibrium does not hold.

Case (2) The equilibrium firm locations are corner solutions. If the equilibrium outcome is a corner solution, then firm A must be indifferent about implementing PP or not, which leads to the following indifference condition:

$$\frac{t(x_B - x_A)(x_A + x_B)^2}{4} - F = \frac{t(x_B - x_A)(x_A + x_B)^2}{8}.$$

In addition to the indifference condition, we must also make sure that firm A has no incentive to deviate. Direct algebra suggest that $3x_A = x_B$. It yields then $x_A = \sqrt[3]{\frac{F}{4t}}$ and $x_B = 3\sqrt[3]{\frac{F}{4t}}$. We find that the equilibrium holds whenever $\frac{t}{54} \leq F \leq \frac{t}{2}$. Q.E.D.

Appendix B: Additional Numerical Examples

B.1. The PP implementation is very low

We start with cases in which the PP implementation cost is sufficiently low. Consider the following numerical examples: (1) The PP implementation cost is linear: $F = 0.01\alpha t$, and (2) the PP implementation cost is quadratic: $F = 0.01\alpha t^2$. Our analysis shows that, in both cases, the equilibrium firm locations are given by

$$x_A = \frac{5}{4} - \frac{3}{2+\alpha}, \;\; x_B = 1 - x_A.$$

This is because, when PP implementation cost is low, both firms always implement PP, and the resulting equilibrium outcome is an interior solution.

B.2. The PP implementation cost is relatively low

Consider first the case in which the PP implementation cost is linear: $F = 0.05\alpha t$. Numerical analysis suggests that the equilibrium firm locations are

$$x_A = \begin{cases} \frac{5}{4} - \frac{3}{2+\alpha} & \text{if } \alpha \leq 0.5467, \\ \frac{21-16\alpha-\alpha^2}{20(3-\alpha)} & \text{otherwise.} \end{cases} \qquad x_B = 1 - x_A.$$

Consider next the case in which the PP implementation cost is quadratic: $F = 0.05\alpha^2 t$. Numerical analysis suggests that the equilibrium firm locations are

$$x_A = \begin{cases} \frac{5}{4} - \frac{3}{2+\alpha} & \text{if } \alpha \leq 0.7018, \\ \frac{30-19\alpha-6\alpha^2-\alpha^3}{20(3-\alpha)} & \text{otherwise.} \end{cases} \qquad x_B = 1 - x_A.$$

In both cases, when α is low, the PP implementation cost is also low and both firms always implement PP. The resulting equilibrium positions are interior solutions. When α is high, the PP implementation cost is moderate. Both firms carefully choose their positions to commit to not implementing PP. The equilibrium is a corner solution, and the firms are indifferent about whether to implement PP.

B.3. The PP implementation cost is moderate

Consider first the case in which the PP implementation cost is linear: $F = 0.1\alpha t$. The equilibrium firm positions are

$$x_A = \begin{cases} \frac{5}{4} - \frac{3}{2+\alpha} & \text{if } \alpha \leq 0.3304, \\ \frac{6-11\alpha-\alpha^2}{10(3-\alpha)} & \text{if } 0.3304 \leq \alpha \leq 0.9352, \\ -\frac{1}{4} & \text{otherwise.} \end{cases} \quad x_B = 1 - x_A.$$

Consider next the case in which the PP implementation cost is quadratic: $F = 0.1\alpha^2 t$. The equilibrium firm positions are

$$x_A = \begin{cases} \frac{5}{4} - \frac{3}{2+\alpha} & \text{if } \alpha \leq 0.5473, \\ \frac{15-14\alpha-6\alpha^2-\alpha^3}{10(3-\alpha)} & \text{if } 0.5473 \leq \alpha \leq 0.9680, \\ -\frac{1}{4} & \text{otherwise.} \end{cases} \quad x_B = 1 - x_A.$$

In both cases above, when α is low, the PP implementation cost is also low. The low PP implementation cost motivates both firms to implement PP, and the resulting equilibrium is an interior solution. When α is moderate, the cost of implementing PP becomes higher, and the firms choose low differentiation to commit to not implementing PP. The equilibrium is a corner solution in which either firm is indifferent about whether to implement PP. Lastly, when α is high, the cost of implementing PP is also high, and neither firm implements PP. The equilibrium is an interior solution.

B.4. The PP implementation cost is high

Consider first the case in which the PP implementation cost is linear: $F = 0.3\alpha t$. The equilibrium firm locations are

$$x_A = -\frac{1}{4}, \;\; x_B = \frac{5}{4}.$$

Given the high PP implementation cost, the firms always forgo implementing PP, and the resulting equilibrium is an interior solution.

Consider next the case in which the PP implementation cost is quadratic: $F = 0.3\alpha^2 t$. The equilibrium firm locations are

$$x_A = \begin{cases} \frac{5}{4} - \frac{3}{2+\alpha} & \text{if } \alpha \leq 0.3320, \\ \frac{15-32\alpha-18\alpha^2-3\alpha^3}{10(3-\alpha)} & \text{if } 0.3320 \leq \alpha \leq 0.5068. \\ -\frac{1}{4} & \text{otherwise.} \end{cases} \quad x_B = 1 - x_A.$$

Note that even though the cost parameter is high (0.3), the actual cost $F = 0.3\alpha^2 t$ is relatively low when α is low. As such, we still observe three regions for the equilibrium outcome: When α is low, both firms always implement PP, and the equilibrium is an interior solution. When α is moderate, the firms choose their locations to avoid implementing PP, and the equilibrium is a corner solution. In equilibrium, the firms are indifferent about implementing PP or not. Lastly, when α is high, the firms never implement PP, and the resulting equilibrium is, again, an interior solution.

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