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Abstract

We study a model of behavior-based price discrimination where firms can agree to share customer information that can be used for personalized pricing. We show that firms are better off sharing customer information as it softens up-front competition when they gather information, consumers are worse off as a result, but total surplus can increase thanks to the improved quality of matching between firms and consumers.

Keywords: Information sharing, behavior-based price discrimination, personalized pricing

JEL Classification Number: D43, L13

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1 Introduction

Over the past several decades, the remarkable advances in digital technologies have enabled firms to have access to a vast amount of consumer data at the granular level. The availability of such data in conjunction with powerful machine-learning tools can be a potential source of competitive advantage.[1] While there are many ways firms can gather such data, one important channel in various service industries such as retail, banking and finance, hospitality and travel has been customers' past purchase histories.[2] Such information can provide firms with the opportunities for behavior-based, or history-dependent, price discrimination (Chen (2005), Fudenberg and Villas-Boas (2006)). In the crudest form, firms can exercise third-degree price discrimination with two market segments, existing and new customers (Chen (1997), Fudenberg and Tirole (2000)). As the quality of information improves, the segmentation of existing customers can be further refined (Liu and Serfes (2004)), leading to personalized pricing in the limit. While personalized pricing may be in limited use in practice, it is becoming more prevalent in some industries thanks to the availability of big data and finer-grained analysis, and has been drawing attention from policy circles.[3]

As data collection and usage often occurs across competing firms, opportunities to share consumer data naturally exist. For example, the airline and tourism industry relies on code-sharing to exchange tourism data across firms. Firms intending to share information can also utilize a third party for which participants voluntarily provide their data, which is then aggregated.[4] Information sharing also exists in the banking industry in the form of open banking, where participating banks can share and leverage customer data to promote the development of new apps and services. Consumer benefits from open banking, it is envisaged, include more personalized services, innovation in fintech and banking apps, and increased competition among banks.[5] While it seems intuitive that information sharing may increase competition, the full effect of information sharing on firm behavior is more subtle. In particular, the expectation of intensified competition due to

[1] "When data creates competitive advantage", *Harvard Business Review*, January-February, 2020.

[2] Relevant information can be gathered using various loyalty programs or payment records. A rich set of data can be also collected online by tracking customers' search and browsing histories. See, for example, "How companies learn your secrets", *The New York Times*, February 16, 2012; "Little brother", *The Economist*, September 11, 2014.

[3] For the examples of personalized pricing used by airlines, grocery chains, online travel portals, see "Different customers, different prices, thanks to big data," *Forbes*, March 26, 2014; "How retailers use personalized prices to test what you're willing to pay", *Harvard Business Review*, October 20, 2017. Ezrachi and Stucke (2016) provide more examples. For relevant policy discussions, see CEA (2015) or "Personalized pricing in the digital era", OECD, November 28, 2018.

[4] For example, STR, formerly known as Smith Travel Research, provides such a service for the hospitality industry. Firms may also join database co-ops where they can pool their databases. See Liu and Serfes (2006) for more discussions on database co-ops.

[5] "Data sharing and open banking", *McKinsey & Company*, July 2017. See also BIS (2019).

information sharing will affect firms' incentives to invest in and gather customer information in the first place.

This paper studies a dynamic model of behavior-based price discrimination to address how the possibility of information sharing affects competition both at the stage of information gathering and at the stage when information is shared for common use. Information sharing does not have bite if competing firms are under symmetric information. This is the case in models of behavior-based price discrimination such as Fudenberg and Tirole (2000) where firms compete in third-degree price discrimination. Thus our model builds on Choe et al. (2018) where competition is in personalized pricing. We extend the model in Choe et al. (2018) by allowing the competing firms to share customer information if they so choose. After firms make information sharing decisions, the ensuing stages are then as follows: in the first period, firms compete à la Hotelling, at the end of which they acquire full information on all of their customers; in the second period, firms compete using a mix of personalized prices and uniform price. If they agreed on information sharing, the second-period competition is under symmetric information; otherwise, each firm uses information only on its previous customers during second-period competition.

Our main findings can be summarized as follows. First, information sharing intensifies competition in the second period in the sense that the total industry profit is lower than without information sharing. More specifically, given that there are two asymmetric equilibria without information sharing, a firm with a larger market share in the first period, say firm A, is worse off in the second period while the other firm (firm B) is better off in the second period. It is because information sharing allows both firms to offer personalized prices to all consumers, rather than their own first-period customers only, which removes the strategic advantage firm A enjoys in the absence of information sharing. On the other hand, the expectation of information sharing softens competition in the first period. Without information sharing, firms have incentives to invest in customer information by competing for a larger market share in the first period, which they can leverage to their advantage in the second period. Information sharing eliminates such incentives, softening competition and making both firms better off than without information sharing. Thus information sharing presents a potential trade-off: by sharing information, firms collectively earn greater profit today at the expense of future profit. This might suggest that information sharing is attractive only when firms are sufficiently impatient. However, we find that information sharing is preferred by both firms across all levels of patience: the extra profit earned in the first period with information sharing more than offsets the profit loss in the second period for firm A while firm B is better off in both periods. Thus information sharing is individually rational for both firms.

While firms are better off with information sharing, consumers are worse off in the sense that the discounted sum of consumer surpluses is smaller when firms share information. This is expected given that information sharing softens overall price competition. In contrast, information sharing increases total surplus. This is again due to softened price competition, which reduces socially inefficient poaching of rival's customers and improves the quality of matching between consumers and firms.

We also discuss the case where firms compete in third-degree price discrimination in the second period. As explained previously, information sharing is irrelevant in this case. Compared to the case with information sharing under personalized pricing, we find that firms are better off but consumers are worse off, and total surplus is also lower. The first two findings are consistent with the standard result that firms are better off when price competition is based on coarser levels of customer information. When competition is in third-degree price discrimination, there is socially inefficient two-way customer poaching as in Fudenberg and Tirole (2000), from which follows that total surplus is lower than when firms compete in personalized pricing.

We extend our analysis to the case where firms endogenously choose their locations after the (dis)agreement on information sharing but before price competition. As the analysis for general values of discount factors is not possible, we follow Choe et al. (2018) and focus on the case where consumers are myopic and firms are forward-looking. Even in this case, information sharing continues to be individually rational for both firms. The flipside is that consumers are worse off when firms share information. On the other hand, total surplus is lower with information sharing in this case. It is because location choice without information sharing makes firms move closer to each other as a result of aggressive positioning, which is most pronounced when firms are forward-looking. This reduces the average transportation cost consumers incur, which is a proxy for total surplus when the market is fully covered, as is the case in our model.

Our work makes contributions to the literature in several important ways. First, we enrich the existing literature on behavior-based price discrimination by incorporating firms' decisions on information sharing and product choice. Second, the existing literature on information sharing reviewed in the next section shows that customer information sharing can be an equilibrium outcome only if there are sufficient asymmetries in brand loyalties, product differentiation, or consumer preferences. In contrast, we show information sharing can emerge in equilibrium in the symmetric case if firms can pre-commit to information sharing before they gather information. This may be taken as an explanation for the prevalence of institutions such as database co-ops or open banking, in which otherwise similar firms join and share customer information. Finally, our welfare analysis shows a clear trade-off between consumer surplus and total surplus that results from information sharing. This can shed light on possible regulations that govern customer information sharing among competing firms. Of course, this is subject to a caveat that we focus on the use of customer information for pricing purposes only. Nor do we consider other important issues such as privacy.

The rest of the paper is organized as follows. The next section provides a brief review of the related literature. Section 3 presents our baseline model, which is analyzed in Section 4. In Section 5, we extend the baseline model to the case where product choice is endogenous. Section 6 concludes the paper. Appendix contains proofs not provided in the main text.

2 Related Literature

Our work is most closely related to two strands of literature. First, the literature on behavior-based price discrimination finds that behavior-based price discrimination generally hurts firms by intensifying competition, unless there are sufficient heterogeneities at the firm- or consumer level. This is true whether competition in third-degree price discrimination (Chen (1997), Villas-Boas (1999), Fudenberg and Tirole (2000), Pazgal and Soberman (2008), Esteves (2009a)) or in personalized pricing (Zhang (2011), Choe et al. (2018)).[6] Choe et al. (2018) show further that competition is intensified more when price discrimination is based on finer levels of consumer information, implying that competition in personalized pricing hurts profitability more than competition in third-degree price discrimination. We add to this strand of literature by allowing firms a possibility to share customer information.[7]

We also contribute to a growing literature on information sharing in oligopoly. The earlier literature considered information sharing about demand or cost conditions (e.g., Gal-Or (1985), Shapiro (1986), Li (2002), Shaffer and Zettelmeyer (2002), or Armantier and Richard (2003)). The main focus in these studies is how information sharing can allow firms to make better output or pricing decisions under cost or demand uncertainties. Instead, the focus in our paper is on sharing customer information that can be used for personalized pricing, and how it can alter firms' incentives to gather information as well as the dynamics of ensuing price competition.[8]

Several papers are similar to ours in studying information sharing as it relates to behavior-

[6] For survey of the literature, see Chen (2005), Fudenberg and Villas-Boas (2006), or Esteves (2009b).

[7] Chen et al. (2019) and Garella et al. (2020) also directly extend Choe et al. (2018) to different directions, personalized pricing with active consumers and a vertically differentiated duopoly.

[8] Awaya and Krishna (2020) show that information sharing in an oligopoly, even at an aggregate level, can improve monitoring and facilitate greater coordination. We also find that firms benefit from information sharing since committing to information sharing reduces upfront competition at the information acquisition stage. The underlying difference in these mechanisms stems from the fact that we consider behavior-based price discrimination while Awaya and Krishna (2020) consider unit pricing.

based price discrimination. Liu and Serfes (2006) is the closest to our work. They consider a two-period model where consumer information is obtained first, after which firms can share information before competing in personalized pricing (where relevant) in the second period. They find that information sharing can increase industry profits only when there are large asymmetries in loyal customer base. In addition, profitable information sharing is only one-way. Our work differs from Liu and Serfes (2006) in several respects. First, we allow firms to pre-commit to information sharing before information is gathered and show information sharing occurs in equilibrium with symmetric firms that are horizontally differentiated. Second, information sharing is individually rational, hence we do not need an additional agreement on profit sharing that is needed to support information sharing in Liu and Serfes (2006). Finally, information sharing is two-way in our case in that firms pool their databases for common use.

Among other related studies, Kim and Choi (2010) analyze when information sharing can be beneficial in a two-period model with consumer heterogeneity (goods are substitutes for some consumers and complements for others). de Nijs (2017) considers a two-period model of behavior-based price discrimination with three asymmetric firms and competition in third-degree price discrimination in the second period. Finally, Chen et al. (2001), Shaffer and Zhang (2002), Jentzsch et al. (2013), Shy and Stenbacka (2013), Belleflamme et al. (2020) all use a static model to identify various conditions under which information sharing can benefit firms. But information is exogenously given in these studies. Thus they cannot address how the possibility of information sharing can soften competition at the stage when firms gather information.

3 The Model

There is a linear city with length 1 where consumers are uniformly distributed. In our base model, firms A and B are located at points 0 and 1, respectively.[9] Both firms have constant marginal cost of production, which is normalized to zero.The indirect utility of consumer at $x \in [0,1]$ is $u_i(x) = v - p_i(x) - t(x - x_i)^2$, where v is the gross surplus from purchasing a product, $p_i(x)$ is firm i's price for consumer x, t is a positive constant, and x_i is the location of firm i ($i = A, B$). As in the standard location models, we assume that v is sufficiently large such that the market is fully covered in equilibrium. Assuming the quadratic transportation cost allows us to solve for a pure-strategy equilibrium when we later consider endogenous location choice by firms (d'Aspremont et al. (1979)).

There are three periods, indexed $\tau = 0, 1, 2$. In $\tau = 0$, firms decide whether or not to share customer information that they gather in $\tau = 1$. We consider the most straightforward manner

[9] We endogenize firm locations in Section 5.

of information sharing: firms agree to establish an information bank where they can deposit their customer information for common use.[10] More specifically, firms play a non-cooperative game where each firm chooses between 'share' and 'not share' subject to the condition that the information bank will be set up if and only if both firms choose 'share'. The latter restriction is to bypass the situation where the game has a unique free-riding equilibrium in which neither firm chooses 'share'. Nonetheless, the game can have multiple pure-strategy equilibria where both firms choose 'share' or at least one firm chooses 'not share'. In this case, we select an equilibrium that Pareto-dominates other equilibria, whenever possible.[11] If firms agree to establish an information bank, then the customer information gathered in $\tau = 1$ can be used by both firms in $\tau = 2$. In $\tau = 1$, firms compete in uniform price, denoted by p_i for $i = A, B$. At the end of $\tau = 1$, firms obtain the information on all their $\tau = 1$ customers.

Competition in $\tau = 2$ proceeds as follows. We use $\mathcal{A}$ ($\mathcal{B}$) to denote the set of customers that firm A (firm B) has information on. If the information bank is established, then each firm knows the locations of its $\tau = 1$ customers as well as the locations of its rival's $\tau = 1$ customers so that $\mathcal{A} = \mathcal{B} = [0, 1]$, since all consumers purchase from one of the firms in $\tau = 1$. In this case, both firms offer personalized prices to all consumers in $\tau = 2$. In contrast, if firms choose not to share customer information, then each firm offers personalized prices only to its $\tau = 1$ customers, but a uniform 'poaching' price to its rival's $\tau = 1$ customers. We denote firm A's personalized prices by $p_A(x)$, for $x \in \mathcal{A}$, and the uniform price by $p_A(\mathcal{B})$; similarly, we denote firm B's personalized prices by $p_B(x)$, for $x \in \mathcal{B}$, and the uniform price by $p_B(\mathcal{A})$. Then, firm A's $\tau = 1$ customers choose between $p_A(x)$ and $p_B(\mathcal{A})$, and firm B's $\tau = 1$ customers choose between $p_B(x)$ and $p_A(\mathcal{B})$.

The timeline for the game is as follows. In $\tau = 0$, firms decide whether or not to share customer information. In $\tau = 1$, firms compete à la Hotelling. In $\tau = 2$, price competition proceeds in two stages. First, as usual in the literature on personalized pricing (e.g., Thisse and Vives (1988), Shaffer and Zhang (2002), Liu and Serfes (2006), Braulin and Valletti (2016), Choe et al. (2018)), firms simultaneously and independently offer their uniform poaching prices (if they are relevant). After that, observing the uniform prices, each firm offers a personalized price to each consumer it recognizes using its customer information. By the sequential decisions on the two types of prices, we can pin down the subgame perfect Nash equilibrium. Besides, the timing structure in $\tau = 2$ reflects the flexibility of changes in personalized prices.

The discount factor of each firm is $\delta_f \in [0, 1]$, and that of each consumer is $\delta_c \in [0, 1]$. The

[10]We are agnostic about whether firms share information directly or through a third party. We observe both outcomes across industries.

[11]Note that we do not consider a cooperative agreement with side payment, as it can lead to a situation where information sharing can work as a collusive device.

discounted sum of firm i's profits is $\Pi_i \equiv \pi_i^1 + \delta_f \pi_i^2$, where the superscripts represent the periods 1 and 2, respectively. Also, the discounted sum of consumer x's utility is $u_x^1 + \delta_c u_x^2$, where u_x^t is the utility level of consumer x in period t.

4 Analysis

4.1 Equilibrium of the Subgame with Information Sharing

We first consider the subgame where information sharing occurs. We solve for the equilibrium using backward induction. In $\tau = 2$, regardless of the $\tau = 1$ outcome, both firms can offer personalized prices to all consumers. This leads to competition in personalized prices as in Thisse and Vives (1988), resulting in the following.

Lemma 1. *If firms agree to share information, then equilibrium prices, profits, and consumer surplus in $\tau = 2$ are given by*

$$p_A^a(x) = t(1-2x) \text{ and } p_B^a(x) = 0 \text{ for } x \le 1/2,$$
$$p_A^a(x) = 0 \text{ and } p_B^a(x) = t(2x-1) \text{ for } x \ge 1/2,$$
$$\pi_A^{2a} = \pi_B^{2a} = \frac{t}{4}, \quad CS^{2a} = v - \frac{7t}{12}, \tag{1}$$

where the superscript a represents the agreement on information sharing.

Proof: See Appendix.

In $\tau = 1$, consumers anticipate that the $\tau = 1$ outcome does not affect the $\tau = 2$ outcome since information sharing renders any difference in firms' $\tau = 1$ market shares irrelevant to $\tau = 2$ competition. Thus consumers delink their $\tau = 1$ purchasing decisions from $\tau = 2$ decisions. Consumer x simply compares $u_x(A)$ and $u_x(B)$ given the uniform prices, p_A^{1a} and p_B^{1a}. This leads to the Hotelling outcome in $\tau = 1$:

$$p_A^{1a} = p_B^{1a} = t, \quad \pi_A^{1a} = \pi_B^{1a} = t/2, \quad CS^{1a} = v - 13t/12.^{12} \tag{2}$$

Based on the above, we can calculate the discounted sum of profits and the discounted sum of consumer surpluses as follows:

$$\Pi_i^a = t/2 + \delta_f(t/4), \; i = A, B; \quad CS^a = (1+\delta_c)v - t(13 + 7\delta_c)/12. \tag{3}$$

[12] More specifically, $CS^{1a} = \int_0^{1/2}(v - t - tx^2)dx + \int_{1/2}^1 (v - t - t(1-x)^2)dx = v - 13t/12$.

4.2 Equilibrium of the Subgame without Information Sharing

For the case where information sharing does not occur, we largely follow Choe et al. (2018). They show that there are two asymmetric equilibria, one being a mirror image of the other. Without loss of generality, we focus on the equilibrium where firm B has a larger market share in $\tau = 1$, hence larger profits in both periods. In this case, profits and consumer surplus in each period are given as follows.

Lemma 2. *Suppose firms choose not to share information. Then, in the equilibrium where firm B has a larger market share in $\tau = 1$, profits and consumer surplus in each period are given by*

$$\pi_A^{1d} = \frac{(4 - 2\delta_c + \delta_f)(12 - 6\delta_c - \delta_f)(6 - 3\delta_c - 2\delta_f)t}{4(12 - 6\delta_c + \delta_f)^2}, \tag{4}$$

$$\pi_B^{1d} = \frac{3(4 - 2\delta_c + \delta_f)((6(2 - \delta_c)^2 - 3(2 - \delta_c)\delta_f - 2\delta_f^2)t}{4(12 - 6\delta_c + \delta_f)^2}, \tag{5}$$

$$CS^{1d} = v - \frac{\Big(36(2 - \delta_c)^2(13 - 6\delta_c) - 12(2 - \delta_c)(5 - 3\delta_c)\delta_f - (179 - 96\delta_c)\delta_f^2 - 12\delta_f^3\Big)\, t}{12(12 - 6\delta_c + \delta_f)^2},$$

$$\pi_A^{2d} = \frac{(36(2 - \delta_c)^2 + 12(2 - \delta_c)\delta_f - \delta_f^2)t}{4(12 - 6\delta_c + \delta_f)^2}, \quad \pi_B^{2d} = \frac{(6 - 3\delta_c + \delta_f)^2 t}{(12 - 6\delta_c + \delta_f)^2}, \tag{6}$$

$$CS^{2d} = v - \frac{(42(2 - \delta_c) + 13\delta_f)\, t}{12(12 - 6\delta_c + \delta_f)},$$

where the superscript d represents the disagreement on information sharing.

Proof: See Appendix.

From the above, we can calculate each firm's discounted sum of profits as $\Pi_i^d = \pi_i^{1d} + \delta_f \pi_i^{2d}$, $i = A, B$, and the discounted sum of consumer surpluses as $CS^d = CS^{1d} + \delta_c CS^{2d}$.

4.3 Equilibrium

In light of the subgame equilibria, we now turn to the information sharing decision that occurs in $\tau = 0$. As explained previously, we consider a simple scenario where firms agree to share information as long as both firms are better off from doing so. This requires us to compare equilibrium profits across the two subgames analyzed above.

We start by comparing profits in each period. In $\tau = 2$, information sharing allows both firms to offer personalized prices to all consumers instead of only to one's $\tau = 1$ customers. This intensifies competition so that the industry profit in $\tau = 2$ is smaller with information sharing. At the individual firm level, however, information sharing increases the $\tau = 2$ profit for one firm but decreases it for the other. Specifically, the firm with a larger $\tau = 1$ market share in the absence of information sharing (firm B by our assumption) sees its $\tau = 2$ profit decrease with information sharing.

Although information sharing intensifies competition in $\tau = 2$, it softens competition in $\tau = 1$. Without information sharing, each firm has an incentive to charge a lower price in $\tau = 1$ to acquire information from a larger customer base, which it can leverage to its advantage in $\tau = 2$. However, an information bank eliminates this incentive, softening competition in $\tau = 1$. As a result, information sharing increases the $\tau = 1$ profit for both firms.

We summarize the above discussions below.

Lemma 3. *In case firms choose not to share information, consider the equilibrium where firm B has a larger market share in $\tau = 1$.*

- *In $\tau = 1$, information sharing results in larger profit for both firms: $\pi_A^{1a} > \pi_A^{1d}$, $\pi_B^{1a} > \pi_B^{1d}$, hence $\pi_A^{1a} + \pi_B^{1a} > \pi_A^{1d} + \pi_B^{1d}$.*
- *In $\tau = 2$, information sharing results in smaller (larger) profit for firm B (firm A), and smaller industry profit: $\pi_A^{2a} > \pi_A^{2d}$, $\pi_B^{2a} < \pi_B^{2d}$, $\pi_A^{2a} + \pi_B^{2a} < \pi_A^{2d} + \pi_B^{2d}$.*

Proof: See Appendix.

The profit comparison across the two periods highlights the tradeoff from information sharing: By establishing an information bank, firms earn higher profit in $\tau = 1$ at the cost of reduced profit in $\tau = 2$. At first glance, this tradeoff suggests that information sharing might be preferred only when firms are impatient. However, it is easy to see that both firms strictly prefer information sharing for all values of discount factor. First, consider firm A. We have already shown above $\pi_A^{1a} > \pi_A^{1d}$ and $\pi_A^{2a} > \pi_A^{2d}$. That is, firm A is better off in both periods with information sharing. Second, firm B is better off in $\tau = 1$ but worse off in $\tau = 2$ with information sharing. But it is straightforward to verify $\pi_B^{1a} - \pi_B^{1d} > \pi_B^{2a} - \pi_B^{2d}$. That is, firm B's gain in $\tau = 1$ more than offsets its (undiscounted) loss in $\tau = 2$. It follows then that firm B strictly prefers information sharing at all values of discount factor. Since $\Pi_i^a \geq \Pi_i^d$ for $i = A, B$, we have the following proposition.

Proposition 1. *In equilibrium, firms choose to share customer information for all values of δ_c and δ_f, which is followed by the standard Hotelling outcome in $\tau = 1$ and the Thisse-Vives outcome in $\tau = 2$ given in Lemma 1.*

4.4 Welfare Analysis

Given that information sharing always occurs in equilibrium, our next question is how information sharing affects welfare. We start with consumer surplus. Information sharing affects consumer surplus through two channels: prices and transportation costs. The price effect on consumer surplus is negative. As we have seen above, firms benefit from softened competition in $\tau = 1$, which more than offsets the adverse effect of increased competition in $\tau = 2$. On the other hand, the average transportation cost decreases with information sharing. Given that firms are located at 0 and 1, the average transportation cost is minimized when the marginal consumer's location is at 1/2, which is indeed the case in both periods when firms share information. Without information sharing, the marginal consumer's location is at 1/2 if and only if $\delta_f = 0$. As we see in the following result, however, the negative price effect dominates the positive transportation cost effect.

Lemma 4. *With information sharing, consumer surplus is smaller in $\tau = 1$ but larger in $\tau = 2$ than without information sharing. For all values of δ_c and δ_f, the discounted sum of consumer surpluses is lower with information sharing: $CS^{1a} < CS^{1d}$, $CS^{2a} > CS^{2d}$, $CS^a < CS^d$.*

Proof: See Appendix.

The effect of information sharing on total surplus is straightforward. Given that the market is always fully covered, total surplus depends only on the average transportation cost. Since information sharing leads to the equilibrium where the average transportation cost is minimized, it follows that total surplus is higher when firms share information. We summarize the discussions so far in the following proposition.

Proposition 2. *For all values of δ_c and δ_f, the discounted sum of consumer surpluses is smaller, but total surplus in each period is larger, when firms share customer information.*

Propositions 1 and 2 highlight the costs and benefits of information sharing from a welfare perspective. Information sharing benefits firms at the cost of consumers, as it softens competition. On the other hand, softened competition reduces socially inefficient poaching of rival's customers, raising total welfare.

4.5 The Degree of Price Discrimination

We briefly discuss how the degree of price discrimination impacts information sharing decisions as well as the resulting profits and welfare. Suppose firms cannot exercise personalized pricing for reasons such as privacy concerns or lack of detailed information. Instead, they rely on third-degree price discrimination by choosing two uniform prices as in Fudenberg and Tirole (2000), one for their own $\tau = 1$ customers and the other for rival's $\tau = 1$ customers. In this case, firms compete in $\tau = 2$ under symmetric information so that information sharing becomes irrelevant. Thus the equilibrium remains the same with or without information sharing. Given this, the following observations are immediate.

First, the discounted sum of profits for each firm under third-degree price discrimination is $\Pi = (3+\delta_c)t/6+\delta_f(5t/18)$. It is easy to see that it is larger than the discounted sum of profits for each firm when firms exercise personalized pricing under information sharing. Thus, even when firms share customer information, they are better off when competition in $\tau = 2$ is in third-degree price discrimination than in personalized pricing. This is consistent with the standard result that firms are better off when price competition is based on coarser levels of customer information. Second, consumer surplus in Fudenberg and Tirole (2000) is $v - (13 + 4\delta_c)t/12$ in $\tau = 1$ and $v - 25t/36$ in $\tau = 2$. It is straightforward to check that consumer surplus in each period is larger than when firms employ personalized pricing under information sharing. Finally, total surplus in Fudenberg and Tirole (2000) is smaller than that under information sharing in our model, simply because there is two-way customer poaching in $\tau = 2$ in Fudenberg and Tirole (2000), resulting in larger average transportation cost than when the marginal consumer's location is at $1/2$. A summary of this comparison is given by the following result:

Proposition 3. *When firms share customer information, competition in personalized pricing leads to larger consumer surplus and total surplus, but smaller profits, than when competition is in third-degree price discrimination.*

5 Endogenous Location Choice

In this section, we extend our model by allowing firms to choose locations. The purpose of this exercise is two-fold. First, we want to check if the qualitative results obtained in the previous section are robust to endogenous product differentiation. Second, the main insight from Choe et al. (2018) is that the endogenous location choice further intensifies competition relative to when firms are located at a maximum distance from each other. We are interested to see if this insight continues to be valid when firms consider information sharing.[13]

To this end, we modify our timeline such that, after the agreement on information sharing but before $\tau = 1$, firms simultaneously and independently choose locations, which remain the

[13] Choe and Matsushima (2020) consider the endogenous location choice in the framework of Fudenberg and Tirole (2000) in which two firms exercise third-degree price discrimination.

same in $\tau = 1, 2$. The rest of the timeline is exactly the same as before. Denote the locations by x_A, x_B and, without loss of generality, we focus on the case $x_A \leq x_B$. Due to the analytical problems in finding closed-form solutions, Choe et al. (2018) consider only the case where $\delta_c = 0$ and $\delta_f = 1$.[14] Thus we focus on this case whenever relevant.

5.1 Equilibrium of the Subgame with Information Sharing

As in the baseline model, we solve the subgame using backward induction. In $\tau = 2$, regardless of the $\tau = 1$ outcome, both firms can offer personalized prices to all consumers. The only difference is that firms are located at x_A and x_B, instead of 0 and 1.

Lemma 5. *If firms agree to share information and location choice is endogenous, then equilibrium prices, profits, and consumer surplus in $\tau = 2$ are given by*

$$
\begin{aligned}
&p_A^{ae}(x) = t(x_B - x_A)(x_A + x_B - 2x) \text{ and } p_B^{ae}(x) = 0 \text{ for } x \leq (x_A + x_B)/2,\\
&p_A^{ae}(x) = 0 \text{ and } p_B^{ae}(x) = t(x_B - x_A)(2x - (x_A + x_B)) \text{ for } x \geq (x_A + x_B)/2,\\
&\pi_A^{2ae} = \frac{(x_B - x_A)(x_A + x_B)^2 t}{4}, \quad \pi_B^{2ae} = \frac{(x_B - x_A)(2 - x_A - x_B)^2 t}{4},\\
&CS^{2ae} = v - \frac{(4 - 9x_A + 6x_A^2 - 3x_B + 6x_B^2)t}{12},
\end{aligned}
$$

where the superscript ae represents the agreement on information sharing under endogenous location choice.

Proof: See Appendix.

In $\tau = 1$, as in the baseline model, firms compete à la Hotelling given locations x_A and x_B. Thus the equilibrium prices, profits, and consumer surplus in $\tau = 1$ are

$$
\begin{aligned}
&p_A^{1ae} = \frac{(x_B - x_A)(2 + x_A + x_B)t}{3}, \quad p_B^{1ae} = \frac{(x_B - x_A)(4 - x_A - x_B)t}{3},\\
&\pi_A^{1ae} = \frac{(x_B - x_A)(2 + x_A + x_B)^2 t}{18}, \quad \pi_B^{1ae} = \frac{(x_B - x_A)(4 - x_A - x_B)^2 t}{18},\\
&CS^{1ae} = v - \frac{(4 - 15x_A + 6x_A^2 + 3x_B + 6x_B^2)t}{12}.
\end{aligned}
$$

Anticipating the above outcomes, firms choose locations by maximizing the discounted sum of profits, $\Pi_i^{ae} = \pi_i^{1ae} + \delta_f \pi_i^{2ae}$, $i = A, B$. This leads to equilibrium locations choices, profits, and consumer surplus given below.

[14] In the Online Appendix, Choe et al. (2018) provide detailed discussions on the conditions for the existence of location equilibria for general values of δ_c and δ_f.

Lemma 6. *If firms agree to share information and location choice is endogenous, then the equilibrium locations are given by*

$$x_A^{ae} = \begin{cases} 0 & \text{if } \delta_f \leq 2/3, \\ \dfrac{3\delta_f - 2}{4(3\delta_f + 2)} & \text{if } \delta_f > 2/3, \end{cases} \quad x_B^{ae} = \begin{cases} 1 & \text{if } \delta_f \leq 2/3, \\ 1 - \dfrac{3\delta_f - 2}{4(3\delta_f + 2)} & \text{if } \delta_f > 2/3. \end{cases} \tag{7}$$

In addition, if $\delta_f = 1$, then equilibrium profit and consumer surplus are given by $\Pi_i^{ae} = 27t/40 = 0.675t$, for $i = A, B$, and $CS^{ae} = (v - 1153t/1200) + \delta_c(v - 613t/1200) \approx (v - 0.961t) + \delta_c(v - 0.511t)$.

Proof: See Appendix.

5.2 Equilibrium of the Subgame without Information Sharing

For the case where firms do not share information, we follow Choe et al. (2018) and consider only the case where $\delta_c = 0$ and $\delta_f = 1$. Once again, there are two asymmetric equilibria, one being a mirror image of the other. Without loss of generality, we focus on the equilibrium that favors firm A.

Lemma 7. *Suppose $\delta_c = 0$ and $\delta_f = 1$. If firms do not share information and location choice is endogenous, then the equilibrium locations, profits, and consumer surplus are given by*

$$\begin{aligned} &x_A^{de} = (2\sqrt{56029} - 347)/621 \approx 0.2, \quad x_B^{de} = 1, \\ &\Pi_A^{de} \approx 0.599t, \quad \Pi_B^{de} \approx 0.412t, \\ &CS^{1de} \approx v - 0.617t, \quad CS^{2de} \approx v - 0.499t, CS^{de} \approx v - 0.617t. \end{aligned}$$

where the superscript de represents the disagreement on information sharing under endogenous location choice.

Proof: See Appendix.

5.3 Equilibrium and Welfare Analysis

In solving the full game, we focus on the case where $\delta_c = 0$ and $\delta_f = 1$, as we did in the previous subsection. When firms share customer information, Lemma 6 shows that each firm's discounted sum of profits is equal to $0.675t$. Then it follows from Lemma 7 that both firms are better off by sharing information. Thus information sharing occurs in equilibrium. It is also worth noting that firms are worse off under endogenous location choice even when they can share customer information: when firms' locations are fixed at 0 and 1, each firm earns profit equal to $0.75t$, as shown in (3). Thus the insight from Choe et al. (2018) continues to be valid: the endogenous location choice further intensifies competition relative to when firms are located at a maximum distance from each other.

Let us now turn to the comparison of consumer surplus. When firms share customer information, the discounted sum of consumer surpluses given in Lemma 6 is $CS^{ae} \approx v - 0.961t$. Without information sharing, we have $CS^{de} \approx v - 0.617t$, as shown in Lemma 7. As in the previous case with fixed locations, consumers are worse-off when firms share customer information.

Finally, the comparison of total surplus is again straightforward. Recall that total surplus depends only on the average transportation cost, or equivalently, the average distance travelled. With information sharing and given $\delta_f = 1$, Equation (7) implies that equilibrium locations are $x_A = 0.05$ and $x_B = 0.95$ so that the marginal consumer's location is $(x_A + x_B)/2 = 1/2$ in both periods. Thus the average distance travelled with information sharing is 0.205 in both periods. Without information sharing, the equilibrium locations are $x_A \approx 0.2$ and $x_B = 1$, and the average distance travelled is 0.195 in $\tau = 1$ and 0.184 in $\tau = 2$ (Choe et al. (2018), p. 5680). Thus total surplus is lower in each period under information sharing when the location choice is endogenous.

This is in contrast to the previous case where locations are fixed at 0 and 1. The intuition is that information sharing softens competition, which in turn reduces the benefits from choosing an aggressive location. Thus firms choose locations close to maximal distance, $x_A = 0.05$ and $x_B = 0.95$. Without information sharing, firms choose more aggressive locations with a view to gaining strategic advantage in $\tau = 2$. Such incentives are most pronounced when $\delta_c = 0$ so that consumers in $\tau = 1$ care about only $\tau = 1$ prices and $\delta_f = 1$ so that firms do not discount their $\tau = 2$ profits. This moves firms closer to each other, $x_A \approx 0.2$, $x_B = 1$ in the equilibrium we considered, reducing the average distance travelled. We summarize these findings formally below.

Proposition 4. *If $\delta_c = 0$ and $\delta_f = 1$ and firms choose location, then information sharing occurs in equilibrium and the consumer surplus and total surplus are smaller than without information sharing.*

6 Conclusion

This paper has studied a model of behavior-based price discrimination where firms can agree to share customer information that can be used for personalized pricing. Our main findings are summarized as follows. First, firms are better off sharing customer information as it softens up-front competition when they gather information, which more than offsets the adverse effect of intensified competition when the information is later used for price discrimination. Second, consumers are worse off as a result of information sharing. Third, information sharing can increase total surplus thanks to the improved quality of matching between firms and consumers. These results hold for all discount factors for consumer and firms. They are also robust to endogenous product differentiation when firms are patient but consumers are myopic.

We also find that the welfare effects of information sharing differ depending on how different levels of aggregating consumer data are used for price discrimination. Specifically, consumer surplus is larger when, following the agreement on information sharing, firms exercise personalized pricing rather than third-degree price discrimination. Total surplus is also larger although firms are worse off under personalized pricing. Given that consumer surplus is larger when firms do not share customer information than when they do, an implication is that the regulation biased in favor of consumer welfare should focus more on information sharing agreements than on price discrimination per se.

We conclude the paper with an important caveat. Our results are driven by our focus on the use of customer information for pricing purposes only. There are other potential benefits from information sharing that we did not consider in this paper. In case of open banking, for example, consumers may benefit from the reduction in switching costs and the development of new apps and more personalized services made possible through information sharing. In addition, information gathering in this paper is a by-product of first-period price competition, rather than a stand-alone management decision. In practice, firms commit significant resources to investment in customer information. These and other aspects of information sharing such as consumer privacy need to be kept in mind for richer understanding of information sharing among competing firms.

Appendix

Proof of Lemma 1: In $\tau = 2$, regardless of the $\tau = 1$ outcome, both firms can offer personalized prices to all consumers as in Thisse and Vives (1988). Thus the equilibrium prices are given by

$$p_A^a(x) = \begin{cases} t(1-x)^2 - tx^2 = t(1-2x) & \text{for } x \le 1/2, \\ 0 & \text{for } x \ge 1/2, \end{cases}$$
$$p_B^a(x) = \begin{cases} 0 & \text{for } x \le 1/2, \\ tx^2 - t(1-x)^2 = t(2x-1) & \text{for } x \ge 1/2. \end{cases}$$

From the above, we can calculate resulting profits as

$$\pi_A^{2a} = \int_0^{1/2} t(1-2x)dx = \frac{t}{4}, \quad \pi_B^{2a} = \int_{1/2}^1 t(2x-1)dx = \frac{t}{4}.$$

The consumer surplus in $\tau = 2$ is then

$$CS^{2a} = \int_0^{1/2} (v - p_A^a(x) - tx^2)dx + \int_{1/2}^1 (v - p_B^a(x) - t(1-x)^2)dx = v - \frac{7t}{12}.$$

□

Proof of Lemma 2: From Lemma 1 in Choe et al. (2018), the $\tau = 1$ prices and the marginal consumer's location z are as follows:

$$p_A^{1d} = \frac{(4 - 2\delta_c + \delta_f)(6 - 3\delta_c - 2\delta_f)t}{2(12 - 6\delta_c + \delta_f)}, \quad p_B^{1d} = \frac{\left(6(2-\delta_c)^2 - 3(2-\delta_c)\delta_f - 2\delta_f^2\right)t}{2(12 - 6\delta_c + \delta_f)},$$
$$z^d = \frac{12 - 6\delta_c - \delta_f}{2(12 - 6\delta_c + \delta_f)} \ (\le 1/2).$$

Then firms' $\tau = 1$ profits are $\pi_A^{1d} = p_A^{1d} z^d$ and $\pi_B^{1d} = p_B^{1d}(1 - z^d)$, leading to the expressions given in Lemma 2. The consumer surplus in $\tau = 1$ is

$$\begin{aligned} CS^{1d} &= \int_0^z (v - p_A^{1d} - tx^2)dx + \int_z^1 (v - p_B^{1d} - t(1-x)^2)dx \\ &= v - \frac{\left(36(2-\delta_c)^2(13 - 6\delta_c) - 12(2-\delta_c)(5 - 3\delta_c)\delta_f - (179 - 96\delta_c)\delta_f^2 - 12\delta_f^3\right)t}{12(12 - 6\delta_c + \delta_f)^2}. \end{aligned}$$

From Proposition 1 in Choe et al. (2018), the $\tau = 2$ prices are as follows:

$$p_A^{2d}(x) = \begin{cases} (1-2x)t & \text{if } x \in \left[0, \frac{12 - 6\delta_c - \delta_f}{2(12 - 6\delta_c + \delta_f)}\right], \\ \frac{\delta_f t}{12 - 6\delta_c + \delta_f} & \text{if } x \in \left[\frac{12 - 6\delta_c - \delta_f}{2(12 - 6\delta_c + \delta_f)}, 1\right], \end{cases}$$

$$p_B^{2d}(x) = \begin{cases} 0 & \text{if } x \in \left[0, \dfrac{3(2-\delta_c)}{12-6\delta_c+\delta_f}\right], \\ \left(2x - \dfrac{6(2-\delta_c)}{12-6\delta_c+\delta_f}\right)t & \text{if } x \in \left[\dfrac{3(2-\delta_c)}{12-6\delta_c+\delta_f}, 1\right]. \end{cases}$$

Given the above, firm A serves consumers on $[0, 3(2-\delta_c)/(12-6\delta_c+\delta_f)]$ and firm B serves the rest. From this follow the profits and consumer surplus in $\tau = 2$ given in Lemma 2. □

Proof of Lemma 3: For $\tau = 2$, equations (1) and (6) imply that

$$(\pi_A^{2a} + \pi_B^{2a}) - (\pi_A^{2d} + \pi_B^{2d}) = \frac{\delta_f(24 - 12\delta_c + \delta_f)t}{4(12 - 2\delta_c + \delta_f)^2} < 0,$$

$$\pi_A^{2a} - \pi_A^{2d} = \frac{\delta_f^2 t}{2(12-6\delta_c+\delta_f)^2} > 0, \quad \pi_B^{2a} - \pi_B^{2d} = -\frac{3\delta_f(8-4\delta_c+\delta_f)t}{4(12-6\delta_c+\delta_f)^2} < 0.$$

For $\tau = 1$, equations (2), (4), and (5) imply that

$$\pi_A^{1a} - \pi_A^{1d} = \frac{(36(2-\delta_c)^2\delta_c + 12(4-\delta_c)(2-\delta_c)\delta_f + (24-11\delta_c)\delta_f^2 - 2\delta_f^3)t}{4(12-6\delta_c+\delta_f)^2} > 0,$$

$$\pi_B^{1a} - \pi_B^{1d} = \frac{(36(2-\delta_c)^2\delta_c + 24(2-\delta_c)\delta_f + (44-21\delta_c)\delta_f^2 + 6\delta_f^3)t}{4(12-6\delta_c+\delta_f)^2} > 0.$$

□

Proof of Lemma 4: From equations (1), (2), and (3) and Lemma 2, we have

$$CS^{1a} - CS^{1d} = -\frac{t\left(18(2-\delta_c)^2\delta_c + 3(6-\delta_c)(2-\delta_c)\delta_f + 8(2-\delta_c)\delta_f^2 + \delta_f^3\right)}{(6(2-\delta_c)+\delta_f)^2} < 0,$$

$$CS^{2a} - CS^{2d} = \frac{t\delta_f}{2(6(2-\delta_c)+\delta_f)} > 0,$$

$$CS^{a} - CS^{d} = -\frac{t\left(36(2-\delta_c)^2\delta_c + 12(3-\delta_c)(2-\delta_c)\delta_f + (32-17\delta_c)\delta_f^2 + 2\delta_f^3\right)}{2(6(2-\delta_c)+\delta_f)^2} < 0.$$

□

Proof of Lemma 5: In $\tau = 2$, regardless of the $\tau = 1$ outcome, both firms can offer personalized prices to all consumers as in Thisse and Vives (1988), with the only difference that firms are located at x_A and x_B, instead of 0 and 1. This modifies the equilibrium prices in Thisse and Vives (1988) as follows:

$$p_A^{ae}(x) = \begin{cases} t(x_B - x)^2 - t(x_A - x)^2 = t(x_B - x_A)(x_A + x_B - 2x) & \text{for } x \le (x_A + x_B)/2, \\ 0 & \text{for } x \ge (x_A + x_B)/2, \end{cases}$$

$$p_B^{ae}(x) = \begin{cases} 0 & \text{for } x \leq (x_A + x_B)/2, \\ t(x_A - x)^2 - t(x_B - x)^2 = t(x_B - x_A)(2x - (x_A + x_B)) & \text{for } x \geq (x_A + x_B)/2, \end{cases}$$

The resulting profits in $\tau = 2$ are

$$\pi_A^{2ae} = \int_0^{(x_A+x_B)/2} t(x_B - x_A)(x_A + x_B - 2x)dx = \frac{(x_B - x_A)(x_A + x_B)^2 t}{4},$$

$$\pi_B^{2ae} = \int_{(x_A+x_B)/2}^{1} t(x_B - x_A)(2x - (x_A + x_B))dx = \frac{(x_B - x_A)(2 - x_A - x_B)^2 t}{4}.$$

The consumer surplus in $\tau = 2$ is

$$\begin{aligned} CS^{2ae} &= \int_0^{(x_A+x_B)/2} (v - p_A^{ae}(x) - t(x_A - x)^2)dx + \int_{(x_A+x_B)/2}^{1} (v - p_B^{ae}(x) - t(x_B - x)^2)dx \\ &= v - \frac{(4 - 9x_A + 6x_A^2 - 3x_B + 6x_B^2)t}{12}. \end{aligned}$$

□

Proof of Lemma 6: Given the $\tau = 1$ and $\tau = 2$ subgames, firms choose locations by maximizing the discounted sum of profits given by $\Pi_i^{ae} = \pi_i^{1ae} + \delta_f \pi_i^{2ae}$, $i = A, B$. Solving the first-order conditions, we obtain the following equilibrium locations:

$$x_A^{ae} = \begin{cases} 0 & \text{if } \delta_f \leq 2/3, \\ \dfrac{3\delta_f - 2}{4(3\delta_f + 2)} & \text{if } \delta_f > 2/3, \end{cases} \quad x_B^{ae} = \begin{cases} 1 & \text{if } \delta_f \leq 2/3, \\ 1 - \dfrac{3\delta_f - 2}{4(3\delta_f + 2)} & \text{if } \delta_f > 2/3. \end{cases}$$

Both firms earn the same discounted sum of profits in equilibrium, given by

$$\Pi_i^{ae} = \begin{cases} \dfrac{(2 + \delta_f)t}{4} & \text{if } \delta_f \leq 2/3, \\ \dfrac{3(2 + \delta_f)^2 t}{8(3\delta_f + 2)} & \text{if } \delta_f > 2/3. \end{cases}$$

When $\delta_f = 1$, we have $\Pi_i^{ae} = 27t/40 = 0.675t$. The discounted sum of consumer surpluses is

$$CS^{ae} = \begin{cases} \dfrac{(v - 13t) + \delta_c(v - 7t)}{12} & \text{if } \delta_f \leq 2/3, \\ \left[v - \dfrac{(340 + 588\delta_f + 225\delta_f^2)t}{48(3\delta_f + 2)^2}\right] + \delta_c \left[v - \dfrac{(196 + 300\delta_f + 117\delta_f^2)t}{48(3\delta_f + 2)^2}\right] & \text{if } \delta_f > 2/3. \end{cases}$$

If $\delta_f = 1$, then $CS^{ae} = (v - 1153t/1200) + \delta_c(v - 613t/1200) \approx (v - 0.961t) + \delta_c(v - 0.511t)$. □

Proof of Lemma 7: First, from Lemma 2 in Choe et al. (2018), we can calculate the $\tau = 1$ profits and consumer surplus as follows:

$$\pi_A^{1de} = \frac{(4 + 7x_A + 7x_B)(3 + 2x_A + 2x_B)(x_B - x_A)t}{169},$$

$$\pi_B^{1de} = \frac{(22 - 7x_A - 7x_B)(5 - x_A - x_B)(x_B - x_A)t}{169},$$
$$CS^{1de} = v - \frac{\left(676 - 24x_A(63 - 20x_A) - 516x_B(1 - 3x_B) - 147(x_B - x_A)(x_A + x_B)^2\right)t}{2028}.$$

Based on Proposition 5 in Choe et al. (2018), the $\tau = 2$ profits and consumer surplus are

$$\pi_A^{2de} = \frac{(x_B - x_A)(151(x_A + x_B)^2 + 24(x_A + x_B) - 8)t}{676},$$
$$\pi_B^{2de} = \frac{(x_B - x_A)(12 - 5x_A - 5x_B)^2 t}{169},$$
$$CS^{2de} = v - \frac{\left(52 - 12x_A(11 - 9x_A) - 24x_B(1 - 2x_B) + 21(x_B - x_A)(x_A + x_B)^2\right)t}{156}.$$

In Choe et al. (2018) (Proposition 5), the equilibrium locations that favor firm A are given by $x_A = (2\sqrt{56029} - 347)/621 \approx 0.2$ and $x_B = 1$. Substituting these into the $\tau = 1$ and $\tau = 2$ profits above and noting $\delta_f = 1$, we can calculate each firm's discounted sum of profits as $\Pi_A^{de} = \pi_A^{1de} + \pi_A^{2de} \approx 0.599t$ and $\Pi_B^{de} = \pi_B^{1de} + \pi_B^{2de} \approx 0.412t$. Substituting $x_A \approx 0.2$ and $x_B = 1$ into the consumer surplus in each period, we have $CS^{1de} \approx v - 0.617t$ and $CS^{2de} \approx v - 0.499t$. The discounted sum of consumer surpluses is $CS^{de} = CS^{1de} + \delta_c CS^{2de}$. Thus, when $\delta_c = 0$, we have $CS^{de} \approx v - 0.617t$. □

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