Behavior-Based Personalized Pricing: When Firms Can Share Customer Information*

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Abstract

We study a two-period model of behavior-based price discrimination where firms can agree to share customer information before the first-period competition begins, and the information can be used for personalized pricing in the second-period competition. We show that information sharing is individually rational for firms as it softens upfront competition when information is gathered, consumers are worse off as a result, but total surplus can increase thanks to the improved quality of matching between firms and consumers. These findings are robust to firm asymmetries and varying discount factors for consumers and firms.

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

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1 Introduction

Over the past several decades, the remarkable advances in digital technologies have allowed firms 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 banking and finance, retail, 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 occur among competing firms, opportunities to share consumer data exist. For example, the airline and tourism industry relies on code-sharing to exchange data across firms. Firms intending to share data 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.[5] While it

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

[2] Relevant information can be gathered using 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. Other examples are Nallan, a third-party platform that facilitates data sharing by suppliers of air freight services, and the agrirouter, a universal data exchange platform for farmers and agricultural contractors. Feasey and de Streel (2020) provides comprehensive discussions on data sharing in practice and related legal and regulatory issues. 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] In Section 5.7, we provide more discussions on open banking.

seems intuitive that information sharing may increase competition (Kim and Choi, 2010, Chen et al., 2022), its full effect on firm behavior is more subtle. In particular, the expectation of intensified competition due to 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 competiting firms have the same information set. 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, but extends it in two important directions. First, we allow firms to commit to information sharing before they compete in price. The ensuing stages are then as follows: in the first period, firms compete à la Hotelling, at the end of which each firm acquires full information on all of its own customers; in the second period, they compete using a mix of personalized and uniform prices. If they agreed on information sharing, then both firms use personalized prices for all consumers based on the same, full information; otherwise, each firm sets personalized prices only for its own previous customers and a uniform price for the rest. Second, unlike most existing studies on behavior-based personalized pricing that assume firms with symmetric costs, we consider firms that may differ in their production costs.

Our main findings can be summarized as follows. First, information sharing is an equilibrium outcome in that each firm's discounted sum of profits is larger under information sharing than that in all equilibria without information sharing. The main driver of beneficial information sharing is softened competition in the first period. Although information sharing intensifies competition in the second period by allowing both firms to use personalized pricing for all consumers, the effect is relatively small since, even without information sharing, firms use personalized pricing for their own first-period customers. In sum, the benefits from softened competition in the first period outweigh the costs of intensified competition in the second period. Second, as a robustness check, we consider the case where firms may have different marginal costs of production. We show that the cost asymmetry does not have any effect on our main conclusion; it only determines which firm becomes more aggressive in the first period. However, the cost asymmetry introduces a discontinuity in the set of equilibria in the subgame without information sharing. When the cost difference is small, there continue to exist two asymmetric equilibria as in Choe et al. (2018). But the equilibrium is unique when the cost difference is above a certain threshold. In this equilibrium, the less efficient firm chooses aggressive pricing in the first period and, as a result, there is one-way customer poaching by the more efficient firm in the second period. These results hold for any discount factors for firms and consumers.

While firms are better off with information sharing, consumers are worse off in that the discounted sum of consumer surpluses is smaller when firms share information. The intuition is as follows. Information sharing affects consumer surplus through two channels: prices and the quality of matching between firms and consumers, as reflected in the transportation cost in our Hotelling model. Information sharing increases the quality of matching with less customer poaching in the second period than without information sharing, which benefits consumers. The flip side is that information sharing creates a negative effect for consumers by softening competition in the first period. Given that firms benefit from information sharing, we expect the negative effect to dominate the positive quality-of-matching effect. At the same time, because prices reflect only the division of surplus between firms and consumers, information sharing can increase total surplus thanks to the positive quality-of-matching effect.

We also analyze several further extensions of our model. First, when firms share customer information, competition in third-degree price discrimination leads to larger profits and consumer surplus, but smaller total surplus than when competition is in personalized pricing. Second, we consider the case where the market is only partially covered in the first period. Because the competition-softening benefits of information sharing in the first period are reduced in this case, we find that firms choose not to share information. Third, when consumers' preferences change over time so that customer information gathered in the first period is imperfectly correlated with that in the second period, information sharing continues to be an equilibrium outcome. It is because sharing information with imperfect preference correlation makes competition in the second period less intense but competition in the first period more intense than when preferences are perfectly correlated. Fourth, when firms make information sharing decisions at the end of the first period, we show that they choose not to share information. The cases with partial market coverage and alternative timing of information sharing highlight the main mechanism at work in our model. Namely, the pre-commitment to sharing information before information gathering and the large benefits from softening up-front competition are crucial for our results. It is because the main benefits from information sharing materialize when the agreement to share information softens competition at the stage when firms gather customer information.

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. 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 that information sharing emerges under a robust space of parameters if firms can commit to information sharing before gathering information. This may be taken as an explanation for the prevalence of institutions such as database co-ops or open banking. Third, we extend the literature by allowing firm asymmetries and show how the set of equilibria depends on cost asymmetry. In particular, we provide a precise condition on when multiple equilibria collapse to a unique equilibrium and fully characterize these equilibria. 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 our focus is on the use of customer information for pricing purposes only and, therefore, we do not consider other effects of information sharing.

The rest of the paper is organized as follows. The next section provides a review of the related literature. Section 3 presents our baseline model, which is analyzed in Section 4. We provide additional discussions and extensions to the model in Section 5 and conclude the paper in Section 6. All deferred proofs are contained in Appendix.

2 Related Literature

Our work is most closely related to two strands of literature. First, the literature on behavior-based price discrimination employs a dynamic model in which firms learn customer information from past purchases, which they use for price discrimination in subsequent purchases. The general findings are that behavior-based price discrimination hurts firms by intensifying competition unless there are sufficient heterogeneities at the firm- or consumer level. This is true whether competition is 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, Garella et al., 2021).[6] This literature generally assumes symmetric firms and imposes restrictions on the discount factors for tractability. We add to this literature in two ways. First, we allow firms the possibility to share customer information before price competition. Second, our model allows asymmetric firms (in Section 5.4) as well as general discount factors

[6] For a survey of the literature, see Chen (2005), Fudenberg and Villas-Boas (2006), or Esteves (2009b). Behavior-based price discrimination can benefit firms when there are sufficient heterogeneities at the consumer level (Chen and Zhang, 2009, Shin and Sudhir, 2010, Colombo, 2018) or at the firm level (Bing, 2017, Rhee and Thomadsen, 2017). In a static, but general oligopoly model, Rhodes and Zhou (2021) shows that competition in personalized pricing can benefit firms when the market is not fully covered under uniform pricing.

that may differ between consumers and firms.

Our analysis of the case without information sharing builds on Choe et al. (2018).[7] They study a two-period model of behavior-based price discrimination with symmetric firms when the second-period competition is in personalized pricing. Their main results are that there are two asymmetric equilibria, a more aggressive firm in the first period can select its preferred equilibrium, and profits are lower compared to when the second-period competition is in third-degree price discrimination. We extend Choe et al. (2018) by allowing firms to share customer information and also considering the case where firms may have asymmetric costs. As we show in Sections 5.3 and 5.4, multiple equilibria in Choe et al. (2018) collapse to a unique equilibrium if consumer preferences can vary across periods or as the cost asymmetry increases.

Somewhat related to the above, there is a growing body of literature that studies how product information provided to consumers affects competition and welfare in static settings (Ivanov, 2013, Hwang et al., 2019, Armstrong and Zhou, 2022). For example, Armstrong and Zhou (2022) formalizes the trade-off that more information can reduce preference mismatch but soften competition by amplifying perceived product differentiation. To focus on our main objective of studying firms' incentives to share information, we employ a model that is different in several ways. First, our model is dynamic where product differentiation is exogenously given and commonly known. Second, consumers have full information about their preferences. Third, our focus is on consumer information held by firms, rather than product information that can be provided to consumers.

We also contribute to the 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, 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-

[7] Chen et al. (2020) extends Choe et al. (2018) to the case of personalized pricing in the presence of consumers' identity management. Chen et al. (2022) extends Choe et al. (2018) to the case of personalized pricing that is made possible by data-driven mergers. Garella et al. (2021) extends Choe et al. (2018) by allowing asymmetric firms in a vertically differentiated duopoly but does not consider information sharing.

[8] Awaya and Krishna (2020) shows that information sharing can benefit firms by improving monitoring and facilitating coordination. We also find that firms benefit from information sharing since committing to information sharing softens upfront competition at the information acquisition stage. The main difference is that we consider behavior-based price discrimination while Awaya and Krishna (2020) considers 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 that information sharing occurs in equilibrium at all levels of firm asymmetries including the case of symmetric firms. 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) analyzes 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.[9]

3 The Model

There is a linear city with unit length where firms A and B are located at points 0 and 1, respectively. Both firms have constant marginal cost of production, which is normalized to zero.[10] Consumers are distributed uniformly over the unit interval, live for two periods (indexed $\tau = 1, 2$), and have unit demand in each of the two periods. We call the consumer located at $x \in [0, 1]$ simply consumer x. The utility of consumer x that purchases from firm i in period τ is given by

$$u_i^\tau(x) = v - p_i^\tau(x) - t(x - x_i)^2, \tag{1}$$

[9] The literature on information gathering/sharing is also expanding into other areas, for example, information sharing among bidders (Asker et al., 2020), how the coarseness of information collection impacts monopoly profits (Laussel et al., 2020), and how data intermediaries act as data providers to competing firms (Bounie et al., 2021).

[10] In Section 5.4, we consider the case where firms have different marginal costs and show that our main result on the benefits of information sharing continues to hold.

where v is the gross surplus from the product, $p_i^\tau(x)$ is firm i's price for consumer x in period τ, t is a positive transportation cost that captures the extent of product differentiation, and x_i is the location of firm i, i.e., $x_A = 0,\ x_B = 1$.[11] We assume that v is sufficiently large so that the market is fully covered in equilibrium.[12]

Firms obtain information on their first-period customers. By "information," we specifically mean the consumer's location, which is assumed to stay the same over time.[13] Since firms do not have any information in $\tau = 1$, they can only offer a single price to all consumers. Thus $p_i^\tau(x)$ in (1) reduces to p_i^1 in $\tau = 1$. But in $\tau = 2$, firms know the exact locations of all their $\tau = 1$ customers. Thus they can offer personalized prices to these consumers and a uniform price to all other consumers. For example, firm A chooses $p_A^2(x)$ for its $\tau = 1$ customer x while firm B chooses $p_B^2(x')$ for its $\tau = 1$ customer x'.

To consider information sharing agreements, we add $\tau = 0$ before $\tau = 1$, when firms decide whether or not to share the customer information that they gather in $\tau = 1$.[14] We consider a simple mechanism for information sharing: firms agree to establish an information bank where they can deposit their customer information for common use. 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', which becomes a binding commitment.[15] Commitment to information sharing is commonplace in some industries, the financial sector being a prime example, as it is mandated by regulations.[16]

We also assume that firms do not choose weakly dominated strategies when making information sharing decisions. Notice that unilateral information sharing is never optimal in our model

[11] We assume a quadratic transportation cost to stay consistent with Choe et al. (2018). This allows us to directly draw from their results when firms have symmetric costs, hence simplifies the discussion of the case without information sharing. But it is easy to see that our results are robust to the linear transportation cost structure because the consumer's utility comparison is the same with quadratic or linear transportation costs.

[12] In Section 5.2, we relax the assumption of full market coverage by considering the case where $v < t$.

[13] Section 5.3 studies the case where preferences change over time in that the second-period location is imperfectly correlated with the first-period location.

[14] In Section 5.5, we consider an alternative timing in which firms make information sharing decisions at the end of $\tau = 1$ but before $\tau = 2$.

[15] We do not consider a cooperative agreement with side payments, as it can lead to a situation where information sharing can work as a collusive device.

[16] See our discussions in Section 5.7. Also, deviation from the commitment can be easily detected since, in our duopoly model, information sharing means each firm must have full information in $\tau = 2$. This facilitates enforcement of commitment.

because it creates competition where one firm has superior information in $\tau = 2$.[17] This disadvantages the firm that unilaterally shares information.[18] Thus, there remain only two possibilities: both firms share or neither firm shares. As we show later, 'not share' is weakly dominated by 'share'. 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 this case, both firms have the same, full information in $\tau = 2$ because of our assumption of full market coverage.

The formal timeline of 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 by selecting their uniform prices; consumers make purchase decisions and firms acquire information on their customers. 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, Chen et al., 2020), firms simultaneously and independently offer their uniform prices only to those consumers whose information is not available to the respective firm. After observing the uniform prices, each firm offers personalized prices to each consumer it recognizes. The sequential timing in pricing decisions not only reflects the flexibility in choosing personalized prices, but also allows us to solve for the subgame perfect Nash equilibrium in pure strategies.[19]

The discount factor is denoted by $\delta_c \in [0, 1]$ for consumers and $\delta_f \in [0, 1]$ for firms. We denote the discounted sum of firm i's profits as $\Pi_i \equiv \pi_i^1 + \delta_f \pi_i^2$, where the superscripts represent the periods. Also, we denote the discounted sum of consumer x's utility as $u^1(x) + \delta_c u^2(x)$, where $u^\tau(x)$ is the utility level of consumer x in period τ. In the main text that follows, we focus on the case where $\delta_c = \delta_f = 1$. This is for ease of exposition and clarity of explanations. But our results hold for general values of $\delta_c, \delta_f \in [0, 1]$, as we show in the proof of our main propositions in Appendix.

[17] For example, suppose only firm B shares its information $[z, 1]$ where z is the marginal consumer in $\tau = 1$. Then, in $\tau = 2$, firm A competes with full information while firm B has information on only $[z, 1]$. Because firm A can choose personalized prices on $[z, 1]$ that can be set lower than its uniform price, firm B is worse off by such unilateral information sharing.

[18] If a firm can choose the amount of information to share, that is, a subset of information it has, then there are possibilities of beneficial, unilateral information sharing (Choe et al., 2021).

[19] When firms simultaneously choose uniform and personalized prices, no pure-strategy equilibrium exists in the subgames where only one firm has information (Liu and Serfes, 2004). Chen et al. (2020) (Section 5.5) further shows that all equilibria in the subgames without information sharing are in mixed strategies except when $z = 1/2$.

4 Analysis

We solve the game backward, starting from the subgame that follows the information sharing game in $\tau = 0$. Let $\mathcal{A}$ ($\mathcal{B}$, resp.) denote the set of consumers that firm A (firm B, resp.) has information on in $\tau = 2$. With information sharing, we have $\mathcal{A} = \mathcal{B} = [0, 1]$ thanks to the assumption of full market coverage. Thus firms compete in $\tau = 2$ under full information and offer personalized prices to all consumers. Without information sharing, we have $\mathcal{A} \cup \mathcal{B} = [0, 1]$ but $\mathcal{A} \cap \mathcal{B} = \emptyset$. Thus each firm offers personalized prices only to its $\tau = 1$ customers, but a uniform 'poaching' price to its rival's $\tau = 1$ customers. That is, firm A's price in $\tau = 2$, denoted by $p_A^2(x)$, is personalized for all $x \in \mathcal{A}$, but uniform for $x \in \mathcal{B}$. Likewise, firm B's price in $\tau = 2$, denoted by $p_B^2(x)$, is personalized for $x \in \mathcal{B}$, but uniform for $x \in \mathcal{A}$. In $\tau = 2$, firm A's $\tau = 1$ customer $x \in \mathcal{A}$ chooses between firm A's personalized price and firm B's uniform price, while firm B's $\tau = 1$ customer $x \in \mathcal{B}$ chooses between firm B's personalized price and firm A's uniform price. In $\tau = 1$, firms compete by choosing uniform prices, which we denote by p_A^1 and p_B^1.

4.1 Equilibrium of the subgame with information sharing

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). 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. This leads to the Hotelling outcome in $\tau = 1$. Put together, we have the following.

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

$$p_A^{2a}(x) = \begin{cases} t(1-2x) & \textit{for } x \in \mathcal{A} = [0, 1/2], \\ 0 & \textit{for } x \in \mathcal{B} = [1/2, 1], \end{cases}$$

$$p_B^{2a}(x) = \begin{cases} 0 & \textit{for } x \in \mathcal{A} = [0, 1/2], \\ t(2x-1) & \textit{for } x \in \mathcal{B} = [1/2, 1], \end{cases}$$

$$\pi_A^{2a} = \pi_B^{2a} = t/4, \quad CS^{2a} = v - (7t)/12, \tag{2}$$

where the superscript 'a' indicates the agreement on information sharing. In $\tau = 1$, they are given by

$$p_A^{1a} = p_B^{1a} = t, \quad \pi_A^{1a} = \pi_B^{1a} = t/2, \quad CS^{1a} = v - (13t)/12. \tag{3}$$

Proof: See Appendix.

4.2 Equilibrium of the subgame without information sharing

For the case where information sharing does not occur, we 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 $\tau = 1$. In this case, based on Proposition 1 in Choe et al. (2018) and noting that $\delta_c = \delta_f = 1$, we can derive the following.

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

$$p_A^{2d}(x) = \begin{cases} t(1-2x) & \text{for } x \in \mathcal{A} = [0, 5/14], \\ t/7 & \text{for } x \in \mathcal{B} = [5/14, 1], \end{cases}$$

$$p_B^{2d}(x) = \begin{cases} 0 & \text{for } x \in [0, 3/7], \\ t(14x-6)/7 & \text{for } x \in [3/7, 1], \end{cases}$$

$$\pi_A^{2d} = (47t)/196, \quad \pi_B^{2d} = (16t)/49, \ CS^{2d} = v - (55t)/84, \tag{4}$$

where the superscript 'd' represents the disagreement on information sharing. In $\tau = 1$, they are given by

$$p_A^{1d} = (3t)/14, \quad p_B^{1d} = t/14, \ \pi_A^{1d} = (15t)/196, \ \pi_B^{1d} = (9t)/196, \ CS^{1d} = v - (19t)/84. \tag{5}$$

As explained previously, firm B prices more aggressively in $\tau = 1$ and secures a larger market share, 9/14 to be exact. Although the aggressive pricing results in profit smaller than firm A's in $\tau = 1$, firm B's profit is larger in $\tau = 2$, which more than offsets the smaller $\tau = 1$ profit, given $\delta_f = 1$. Thus, the above equilibrium in consistent with the general insight in Choe et al. (2018) that the more aggressive firm in $\tau = 1$ can force the game to be played to its advantage.

4.3 Equilibrium

We now turn to firms' information sharing decisions in $\tau = 0$. As explained previously, we consider a simple scenario where information is shared if and only if both firms agree, i.e., information sharing is individually rational for each firm. This requires us to compare equilibrium profits across the two subgames analyzed above. The following table summarizes the results in (2), (3), (4), and (5).

Table 1: Profits and consumer surplus with or without information sharing

	π_A^1	π_A^2	π_B^1	π_B^2	CS^1	CS^2
Information sharing	$t/2$	$t/4$	$t/2$	$t/4$	$v-(13t)/12$	$v-(7t)/12$
No information sharing	$(15t)/196$	$(47t)/196$	$(9t)/196$	$(16t)/49$	$v-(19t)/84$	$v-(55t)/84$

As is clear from Table 1, information sharing softens competition in $\tau = 1$, resulting in larger profits for both firms in $\tau = 1$: $\pi_A^{1a} = t/2 > \pi_A^{1d} = (15t)/196$ and $\pi_B^{1a} = t/2 > \pi_B^{1d} = (9t)/196$. Indeed, the softened competition manifests itself in higher prices, as shown in (3) and (5). However, information sharing intensifies competition in $\tau = 2$ by allowing both firms to offer personalized prices to all consumers instead of only to one's $\tau = 1$ customers. As a result, firm B is worse off than without information sharing: $\pi_B^{2a} = t/4 < \pi_B^{2d} = (16t)/49$. But firm A is better off because the equilibrium without information sharing we focus on favors firm B: $\pi_A^{2a} = t/4 > \pi_A^{2d} = (47t)/196$. For both firms, the positive effect of softened competition in $\tau = 1$ is large enough, which results in larger profits than when they do no share information. We can verify this by comparing the discounted sum of profits for each firm. Given $\delta_f = 1$, we have $\Pi_A^a = \pi_A^{1a} + \pi_A^{2a} = (3t)/4 > \Pi_A^d = \pi_A^{1d} + \pi_A^{2d} = (31t)/98$ and $\Pi_B^a = \pi_B^{1a} + \pi_B^{2a} = (3t)/4 > \Pi_B^d = \pi_B^{1d} + \pi_B^{2d} = (73t)/196$. Thus, both firms are better off under information sharing. Although the above discussion was based on the case $\delta_c = \delta_f = 1$, the following proposition holds for all discount factors $\delta_c, \delta_f \in [0, 1]$, as shown in the proof.

Proposition 1. *For all values of $\delta_c, \delta_f \in [0, 1]$, we have $\Pi_i^a \geq \Pi_i^d$ for $i = A, B$ so that the unique equilibrium of the whole game is as follows: in $\tau = 0$, firms agree to share information, which is followed by the Hotelling outcome in $\tau = 1$ and the Thisse-Vives outcome in $\tau = 2$.*

Proof: See Appendix.

The main reason for the beneficial information sharing is that the commitment to information sharing softens competition at the stage of information acquisition. Without the commitment, each firm strives to gain a larger market share in $\tau = 1$ since a larger market share translates to more customer information, which the firm can leverage in $\tau = 2$ when employing personalized pricing. This intensifies competition in $\tau = 1$ which is escalated since prices are strategic complements. Although information sharing intensifies competition in personalized pricing in $\tau = 2$, the effect is relatively small because firms already compete using personalized pricing for their own $\tau = 1$ customers even without information sharing. As we can see from Table 1, the negative effect of information sharing on the $\tau = 2$ profits is relatively small compared to the positive effect on the $\tau = 1$ profits. To summarize, the commitment to share information generates the benefits of softened competition in $\tau = 1$ that outweigh the relatively small costs of intensified competition in $\tau = 2$.

4.4 Welfare

Given that information sharing occurs in equilibrium, our next question is how information sharing affects welfare. We start with consumer surplus denoting consumer surplus under information sharing by $CS^a = CS^{1a} + \delta_c CS^{2a}$ and consumer surplus without information sharing by $CS^d = CS^{1d} + \delta_c CS^{2d}$. In general, information sharing should hurt consumers in $\tau = 1$ but benefit them in $\tau = 2$, precisely because of its differing effect on competition in each period. More specifically, 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 show below, however, the negative price effect dominates the positive transportation cost effect. For the case $\delta_c = 1$, we can calculate CS^a and CS^d from Table 1: $CS^a = v - (5t)/3 < CS^d = v - (37t)/42$. As before, the negative effect of information sharing on consumer surplus holds for general values of δ_c and δ_f.

Lemma 3. *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 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. Simply put, the positive effect of information sharing on total surplus is driven by reduced preference mismatch enabled by information sharing.[20] We summarize the discussions so far in the following proposition.

[20] In Armstrong and Zhou (2022), preference mismatch is reduced when firms optimally choose to disclose

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. But softened competition reduces socially inefficient poaching of rival's customers, raising total welfare.

5 Extensions and Discussions

5.1 The degrees of price discrimination

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 in $\tau = 2$ have the same information set, 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 a larger average transportation cost than when the marginal consumer's location is at 1/2.

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

product information to consumers, which amplifies perceived product differentiation and softens competition. In our model, the effect of information sharing on match quality is driven entirely by price competition because product differentiation is fixed exogenously and commonly known.

in third-degree price discrimination.

5.2 Partial market coverage

Our baseline model assumed large enough v, which ensures that all consumers are served in $\tau = 1$. What happens if the market is not fully covered in $\tau = 1$? As our analysis has shown, the benefits of information sharing are derived from softening competition in $\tau = 1$. Partial market coverage reduces such benefits because some consumers do not purchase in $\tau = 1$, which makes information sharing less attractive than when the market is fully covered.[21] We analyze this case below. First, we assume $v < t$ because the market is fully covered if and only if $v \geq t$ in the Hotelling duopoly. Second, we assume a linear transportation cost and $\delta_c = 0$. It is mainly to simplify analysis because solving the case with partial market coverage is quite complicated with many different outcomes to consider in our two-period model. Assuming $\delta_c = 0$ shuts down one channel of complication by delinking consumers' problems over the two periods. Even with this assumption, the case with partial market coverage leads to several different outcomes, as we describe below.

Suppose $[z_A, z_B]$ is not served in $\tau = 1$. Then, for any $v < t$, we have $z_A < 1/2 < z_B$ with or without information sharing as shown in the proof of Proposition 4, and the outcome in $\tau = 2$ can be divided largely into three cases. First, $[z_A, z_B]$ is fully covered and the marginal consumer is in the interior of $[z_A, z_B]$ and has strictly positive net utility, which we call *interior duopoly*. Second, $[z_A, z_B]$ is fully covered and the marginal consumer is in the interior of $[z_A, z_B]$ but has zero net utility, which we call *corner monopoly*. Third, $[z_A, z_B]$ is not fully covered and each firm serves a fraction of $[z_A, z_B]$, which we call *local monopoly*. As v decreases from t, the outcome changes from interior duopoly to local monopoly with or without information sharing. The following proposition shows that, for all $\tau = 2$ outcomes described above, both firms prefer no information sharing to information sharing.

Proposition 4. *Suppose $\delta_c = 0$ and assume a linear transpiration cost. Then, for all $v < t$, the $\tau = 1$ market is not fully covered with or without information sharing, and neither firm strictly prefers information sharing to no information sharing. Thus, no information sharing is an equilibrium outcome.*

Proof: See Appendix.

[21] Related to this, Rhodes and Zhou (2021) shows that, when the market is partially covered under uniform pricing, competition in personalized pricing benefits firms by enabling them to serve low-value customers who would otherwise be excluded.

The general intuition for the above result can be provided as follows. First, as explained previously, partial market coverage reduces the benefits of information sharing in $\tau = 1$. In $\tau = 2$, firms compete à la Hotelling on $[z_A, z_B]$ with or without information sharing. These Hotelling prices constrain each firm's personalized prices under no information sharing. With information sharing, each firm's personalized price for the customer it serves is constrained by the rival's personalized price offered to that customer. This means that, compared to the case with full market coverage, competition in $\tau = 2$ is not as intense because of the 'buffer' zone, $[z_A, z_B]$, which is true with or without information sharing. Put together, we can conclude that information sharing is less valuable under partial market coverage because the benefits of softened competition in $\tau = 1$ are smaller and its effect in $\tau = 2$ is less pronounced because partial market coverage softens competition in $\tau = 2$ even without information sharing.

However, the above discussion only explains that partial market coverage reduces the benefits of information sharing, but not why firms choose not to share information. For this, observe that consumers' participation constraints impose a cap of $2v - t$ on $p_A^1 + p_A^2$. This means that, as v becomes smaller, competition becomes more intense. When $v = t$, although the market is fully covered, competition is intense in that the Hotelling prices are $p_A^1 = p_B^1 = t/2 < t$, the latter being the Hotelling prices in our baseline model where we assumed v is sufficiently large, or $v > (3t)/2$ to be precise.[22] Thus, when $v = t$, Hotelling competition is already quite intense so that there is not much to gain by achieving this outcome through the information sharing agreement.

5.3 Imperfect correlation of consumer preferences

In our baseline model, we assumed that preferences stay the same in both periods. We now consider the case where preferences are imperfectly correlated across the two periods. For example, some consumers may have their preferences changing over time. In this case, information gathered in $\tau = 1$ is less useful for price discrimination in $\tau = 2$. Thus, compared to the case with perfectly correlated preferences, competition in $\tau = 2$ softens when firms do not share information. However, the anticipation of softened competition in $\tau = 2$ can intensify competition in $\tau = 1$. It is because each firm expects to retain much of its $\tau = 1$ market share in $\tau = 2$ thanks to the softened competition. Put together, the case with imperfectly correlated preferences leads to intense competition in $\tau = 1$ but softened competition in $\tau = 2$ when firms do not share information. Given that the main benefits of information sharing are from softening competition in $\tau = 1$, while the downside of intense competition in $\tau = 2$ exists with or without information sharing, we expect information sharing to be preferred by both firms.

[22] See Chen and Riordan (2008) or Cowan and Yin (2008) for related points.

We formalize the above by considering a simple model of imperfectly correlated preferences following (Armstrong and Vickers, 2010, pp. 52-53). To be precise, we consider a model where a consumer's $\tau = 1$ location is imperfectly correlated with her $\tau = 2$ preference. Suppose that a fraction $\eta \in (0, 1]$ of consumers have preferences changing over time in that, in $\tau = 2$, their preferences are drawn from a new uniform distribution on $[0, 1]$. That is, these consumers move to new locations in the beginning of $\tau = 2$. The remaining fraction of consumers have the same preferences in both periods. For a consumer whose location changes, we assume that firms can observe her new location if they gathered her information in $\tau = 1$ or acquired it through information sharing. This assumption not only renders personalized prices precise meaning but also simplifies analysis.[23] To further simplify analysis, we assume $\delta_c = 0$ and a linear transportation cost, as in Section 5.2.

Proposition 5. *Suppose a fraction $\eta \in [0, 1]$ of consumers have their $\tau = 2$ preferences drawn from a uniform distribution on $[0, 1]$ independently of their $\tau = 1$ preferences, but the remaining consumers have the same preferences in both periods. Suppose $\delta_c = 0$ and assume a linear transpiration cost. Then, for all $\eta \in (0, 1]$,*

- *the subgame without information sharing has a symmetric equilibrium where the $\tau = 1$ prices are $p^1_A = p^1_B = t - \delta_f(8 - \eta)(t/16)$, and the discounted sum of profits is $\Pi_A = \Pi_B = t/2 + \delta_f(2 - \eta)(t/8)$.*
- *the subgame with information sharing has the same equilibrium as the case with perfectly correlated preferences where the $\tau = 1$ prices are $p^1_A = p^1_B = t$, and the discounted sum of profits is $\Pi_A = \Pi_B = t/2 + \delta_f(t/4)$.*
- *both firms prefer information sharing to no information sharing.*

Proof: See Appendix.

When firms do not share information, the symmetric equilibrium in Proposition 5 is in contrast to the asymmetric equilibria in Choe et al. (2018). It is because the existence of consumers whose preferences change substantially alters uniform poaching prices in $\tau = 2$. Suppose preferences stay the same in both periods as in Choe et al. (2018), and consider the case where firm B's $\tau = 1$ market share is larger than $1/2$, i.e., $z < 1/2$. Then firm B's uniform price is zero, where it

[23] When competition is in uniform price as in Armstrong and Vickers (2010), only the aggregate information, not the consumer's precise new location, matters. But the location information matters when competition is in personalized pricing as in our case.

remains as z decreases further to 0. But as z decreases, firm A's poaching price increases, which benefits firm B by allowing it to increase its personalized prices. Given that this outcome is the result of firm B's aggressive pricing that gives firm B a larger market share in $\tau = 1$, firm B does not have incentives to deviate in $\tau = 1$, and nor does firm A. This sustains the asymmetric equilibrium in Choe et al. (2018). Suppose now there are some consumers whose preferences change, and consider again the case where $z < 1/2$. Then, as shown in the proof of Proposition 5, firm B's uniform price is $t/2$ rather than 0, where it remains as z decreases further to 0. In contrast to the case where preferences stay fixed, firm B chooses a positive uniform price even when $z < 1/2$. It is because, when there are consumers with changing preferences, there are some consumers firm B can serve even if their $\tau = 1$ locations were closer to firm A. Although firm A's uniform price is also $t/2$ when z is close to $1/2$, as z decreases further, firm A lowers its uniform price to attract firm B's $\tau = 1$ customers whose preferences do not change. This hurts firm B because its personalized prices need to be decreased in response to firm A's lower uniform price. Therefore, firm B does not benefit much from competing for a larger market share in $\tau = 1$, and the same is true for firm A. This leads to the symmetric equilibrium in Proposition 5.

5.4 Asymmetric costs

This section extends analysis to the case where firms may have different marginal costs. Specifically, we assume that firm A's marginal cost is zero but firm B's marginal cost is $c \geq 0$. This nests our baseline model as a special case where $c = 0$. This asymmetric cost case yields two main results, which are analyzed fully in an earlier version of this paper. Thus, we present only the key results here and refer to Choe et al. (2020) for formal analysis and proofs.

In the subgame without information sharing, the structure of equilibria depends on the cost difference c. When c is below a certain threshold, there continue to exist two pure-strategy equilibria as in Choe et al. (2018). In one equilibrium, the less efficient firm, firm B by our assumption, prices aggressively in $\tau = 1$, as a result of which firm A poaches firm B's $\tau = 1$ customers in $\tau = 2$. We call this the *firm A poaching equilibrium*. In the other equilibrium, firm B poaches firm A's $\tau = 1$ customers in $\tau = 2$, which we call the *firm B poaching equilibrium*. When c is above the threshold, the firm A poaching equilibrium remains as the unique equilibrium. More specifically, we have the following proposition for the case $\delta_c = 0$, $\delta_f = 1$, and $t = 1$.[24]

Proposition 6. *Suppose $\delta_c = 0$, $\delta_f = 1$, and $t = 1$. In the subgame where firms do not share information, there exists a constant $k \approx 0.04$ such that*

[24] This corresponds to Proposition 1 in Choe et al. (2020). But the proposition holds for general values of δ_c, δ_f and c, as proved in Choe et al. (2020).

- *there is a unique firm A poaching equilibrium if and only if $k < c$, in which firm A's market share in $\tau = 1$ is given by $z_I = (11 + 7c)/26$,*
- *if $c \leq k$, then a firm B poaching equilibrium coexists with the firm A poaching equilibrium, in which firm A's $\tau = 1$ market share is given by $z_{II} = (15 + 7c)/26$.*

We can illustrate the above using figures. In Figure 1, the (blue) solid lines represent firm A's best response function with p_{BJ} indicating its discontinuity point, and the (red) dashed lines represent firm B's best response function with p_{AJ} indicating its discontinuity point. In Figure 1, the best response functions intersect twice, hence we have multiple equilibria. In the current example, this corresponds to the case where $c \leq k \approx 0.04$. For example, when $c = 0$, the firm A poaching equilibrium is given by $(p_A, p_B) = (10/13, 8/13)$ with $z_I = 11/26$, and the other equilibrium is its mirror image, as in Choe et al. (2018).

— Insert Figure 1 about here. —

Suppose now c increases. Then firm A becomes less aggressive so that p_{BJ} increases, while firm B becomes more aggressive so that p_{AJ} decreases. As can be seen from Figure 1, this makes the intersection of p_{AII} and p_{BII} less likely, which will eventually leave only the intersection between p_{AI} and p_{BI} as the unique equilibrium. This is shown in Figure 2. For example, when $c = 1/2$, the unique equilibrium is the firm A poaching equilibrium, which is given by $(p_A, p_B) = (12/13, 27/26)$ with $z_I = 29/52$.

— Insert Figure 2 about here. —

Despite the cost difference, the main insight from the symmetric cost case continues to be valid. Namely, for both firms, the benefits from softened competition at the information acquisition stage outweigh the costs of intensified competition when information is used for price discrimination. As a result, information sharing continues to be individually rational. The following is the main result in Choe et al. (2020) that generalizes Proposition 1.

Proposition 7. *For all values of δ_c, δ_f, and c, the unique equilibrium of the whole game is as follows: in $\tau = 0$, firms agree to share information, which is followed by the Hotelling outcome in $\tau = 1$ and the Thisse-Vives outcome in $\tau = 2$. The discounted sum of consumer surpluses under information sharing is smaller than that in either equilibrium without information sharing.*

5.5 Alternative timing

The point in time when the agreement to share information occurs is important in our framework. Suppose firms make decisions to share information at the end of $\tau = 1$ but before $\tau = 2$. Other than this, all other features of our baseline model stay the same. In particular, information sharing occurs if and only if both firms agree to do so. This alternative timing results in no information sharing in equilibrium, as we show below.

Consider $\tau = 2$. With information sharing, we have the Thisse-Vives outcome. Without information sharing, the total industry profit in any equilibrium is bounded below by the total industry profit in the Thisse-Vives equilibrium, which follows from Proposition 2 in Chen et al. (2020). This implies that at least one firm has higher profit than the Thisse-Vives level in any equilibrium without information sharing, and hence will choose not to share information. Given the above and our assumption that information sharing occurs if and only if both firms agree, we can conclude that firms do not reach an agreement to share information at the end of $\tau = 1$. Then, in $\tau = 1$, we have the equilibria as in Choe et al. (2018).

This highlights the mechanism behind our main result. The pre-commitment to information sharing prior to the acquisition of information is crucial because the main benefits from information sharing are to soften competition at the stage when information is gathered. Such benefits disappear when the information sharing agreement follows the stage when firms compete for customer information. Which timing is more plausible in practice depends on different mechanisms for information sharing. For example, when banks apply for the accreditation to participate in open banking, they do so in anticipation of sharing information gathered after their accreditation, rather than sharing information they already have. This is discussed in more detail in Section 5.7. On the other hand, firms may join a database co-op with a view to gaining access to information other members already have.

5.6 Longer time horizon

Our analysis has identified a clear trade-off in information sharing. The benefits come from softened competition in $\tau = 1$ when firms compete to gather customer information, while the costs are due to intensified competition in $\tau = 2$ when firms use information for price discrimination. Given this trade-off, a natural question is whether information sharing continues to be an equilibrium outcome if there are multiple future periods when firms compete using the shared information, which can increase the costs of information sharing.

To address this question and consider the possibility of ongoing information sharing, we follow Rhee and Thomadsen (2017) to expand the range of the discount factors beyond the traditional range of zero to one. In particular, we allow $\delta_c, \delta_f \in [0, 3/2]$ so that the case with $\delta_c, \delta_f \in (1, 3/2]$ offers a way of modelling multiple continuation periods in reduced form. We restrict analysis to the case where $\delta_c, \delta_f \leq 3/2$, which ensures an interior solution for the $\tau = 1$ marginal consumer's location, i.e., $z \in (0, 1)$. Otherwise, one of the firms monopolizes the market in $\tau = 1$ so that information sharing becomes irrelevant.

Given the expanded range of discount factors, we can show that our qualitative results stay the same. That is, each firm prefers information sharing to no information sharing for all values of $\delta_c, \delta_f \in [0, 3/2]$, and that the discounted sum of consumer surpluses is smaller when firms share information.[25]

5.7 Information sharing in practice

Earlier in the paper, we presented several examples of information sharing by firms such as information exchange in the airline industry, database co-ops, and open banking. In this section, we provide some more details on information sharing in practice. We then discuss legal and regulatory issues related to information sharing in general.

Information sharing among competitors is mandated by government regulations in several industries. In Europe, for example, information sharing is imposed in automotive, banking and finance, electronic communications, energy, and postal services (Feasey and de Streel, 2020). As discussed previously, information sharing in banking can take the form of open banking, which is mandated in Australia (Consumer Data Right or CDR), and the UK and EU (UK Open Banking Standard, and Payment Services Directive Two).[26] In Australia, in particular, the CDR Register and Accreditation Application Platform provides a portal where businesses can apply to be accredited, and create a trusted data environment where encrypted data is shared only among accredited participants. This application and accreditation process can be taken to reflect the stage $\tau = 0$ in our model. Although our stylized model does not capture important features of banking such as the interaction between deposit and lending markets, screening and monitoring, evidence suggests that open banking leads to more personalized offers and services in banking,[27] the latter being the main role of information in our model.

[25] The details are available from the authors.

[26] Australia goes even further to mandate data sharing beyond the financial sector. The banking sector is the first industry where the CDR applies, followed by the energy sector, with the telecommunications sector expected to follow (https://www.accc.gov.au/focus-areas/consumer-data-right-cdr-0).

[27] For evidence, see, for example, https://fintechmagazine.com/financial-services-finserv/rise-open-banking-how-big-data-changing-fintech. Vives and Ye (2022) provides a spatial model of bank competition that explicitly takes into account the effects of information technology.

In addition to the mandated information sharing mentioned above, there is evidence of business-to-business (B2B) information sharing in other industries as well. As an example, Arnaut et al. (2018) reports results from a survey conducted in 2017-2018 covering 129 companies across 31 countries in the European Economic Area. The survey covers firms with various sizes from six business sectors: data-generating driving (i.e., automotive, transport and logistics), smart agriculture, smart manufacturing, telecom operators, smart living environments (i.e., home automation, sensors, robotics, or wearable technology), and smart grids & meters. Although the report does not say whether firms use shared information for pricing purposes, it finds that most B2B information sharing is within the same business sector and that firms choose to share information depending on their business strategies.

Whether or not information sharing among competitors can potentially breach competition laws depends on the type of information that is shared. Some information sharing can be vital for innovations leading to new products and services, while sharing other information can facilitate collusion. The key issue is then weighing the beneficial effects of information sharing against the adverse effects on competition. In the EU, for example, Article 101(1) of the Treaty on the Functioning of the European Union (TFEU) can limit information sharing among competitors if it restricts competition that cannot be justified under Article 101(3) as having beneficial effects that outweigh anticompetitive effects (Feasey and de Streel, 2020, pp. 40-41). Lundqvist (2018, p. 150) classifies information roughly into three types: (i) pricing and output information, (ii) consumers' and general market information, and (iii) more technology- or know-how-oriented information. Sharing the first type of information is most likely harmful but sharing the third type is most likely innocuous. The second type of information falls in the grey area, which is relevant to our paper where the primary purpose of customer information sharing is price discrimination. While some legal scholars seem to have concerns about information sharing that can facilitate price discrimination (Lundqvist, 2018, p. 152), whether it is pro- or anti-competitive depends on market environments. A dominant firm exercising price discrimination can generally harm consumers. However, as is well-known and also shown in the analysis of $\tau = 2$ pricing game in this paper, information sharing in oligopoly can intensify competition when its primary use is for price discrimination. Rather than price discrimination per se, it is the anticipation of information sharing that can restrict competition at the stage when firms compete to gain customer information. Thus, whether information sharing can be pro- or anti-competitive needs to be understood in a dynamic context within a clearly defined market environment.

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 upfront 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 consumers and firms and are robust to a variety of cost asymmetries across firms. An additional finding is how the set of equilibria changes as cost asymmetries change. Specifically, there are multiple equilibria as in Choe et al. (2018) when the cost difference is small, but the equilibrium is unique when the cost difference is above a certain threshold.

We have considered several other extensions of our baseline model to discuss whether information sharing continues to be an equilibrium outcome. We find that firms prefer information sharing to no information sharing when some consumers have preferences changing over time, or when the time horizon is extended so that shared information has more lasting effect of intensifying competition. On the other hand, firms choose not to share information when the market is not fully covered at the stage where information is gathered, or when the agreement to share information follows the information gathering stage. These extensions reconfirm the key mechanism at work. The pre-commitment to sharing information before information gathering is crucial because the main benefits from information sharing are to soften competition at the stage when information is gathered.

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. For example, information sharing can benefit consumers through the reduction in switching costs, and the development of new apps and more personalized services. 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 investments in customer information. These and other aspects of information sharing need to be kept in mind for a richer understanding of information sharing among competing firms.

Appendix

In the main text, we focused mostly on the case where $\delta_c = \delta_f = 1$. In this appendix, we state and prove the results for general values of $\delta_c, \delta_f \in [0, 1]$, whenever relevant.

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

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

From the above, we can calculate equilibrium 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

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

In $\tau = 1$, the Hotelling equilibrium prices and profits are straightforward. The consumer surplus is then $CS^{1a} = \int_0^{1/2}(v - t - tx^2)dx + \int_{1/2}^1 (v - t - t(1-x)^2)dx = v - (13t)/12$. ∎

Proof of Proposition 1: Without information sharing, the equilibrium that favors firm B is as given in Proposition 1 in Choe et al. (2018). Based on this, we can calculate the profits in each period as follows:

$$\begin{aligned} \pi_A^{1d} &= \frac{(4 - 2\delta_c + \delta_f)(12 - 6\delta_c - \delta_f)(6 - 3\delta_c - 2\delta_f)t}{4(12 - 6\delta_c + \delta_f)^2}, \\ \pi_B^{1d} &= \frac{3(4 - 2\delta_c + \delta_f)((6(2-\delta_c)^2 - 3(2-\delta_c)\delta_f - 2\delta_f^2)t}{4(12 - 6\delta_c + \delta_f)^2}, \\ \pi_A^{2d} &= \frac{(36(2-\delta_c)^2 + 12(2-\delta_c)\delta_f - \delta_f^2)t}{4(12 - 6\delta_c + \delta_f)^2}, \\ \pi_B^{2d} &= \frac{(6 - 3\delta_c + \delta_f)^2 t}{(12 - 6\delta_c + \delta_f)^2}. \end{aligned}$$

Since $\Pi_i^k = \pi_i^{1k} + \delta_f \pi_i^{2k}$ for $i = A, B$ and $k = a, d$, we have

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

$$\Pi_B^a - \Pi_B^d = \frac{(36(2-\delta_c)^2\delta_c + 24(2-\delta_c)\delta_f + (44-21\delta_c)\delta_f^2 + 6\delta_f^3)t}{4(12-6\delta_c+\delta_f)^2} - \frac{3\delta_f(8-4\delta_c+\delta_f)t}{4(12-6\delta_c+\delta_f)^2} > 0.$$

Thus both firms choose information sharing. The rest of the proposition follows from the discussions in Section 4.1. ∎

Proof of Lemma 3: With information sharing, consumer surplus in each period is given in (2) and (3). Without information sharing and for general values of δ_c and δ_f, we can calculate consumer surplus in each period as follows:

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

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

From the above, we obtain

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

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

$$CS^a - (CS^{1d} + \delta_c CS^{2d})$$

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

∎

Proof of Proposition 4: Suppose $[z_A, z_B]$ is not served in $\tau = 1$ where $0 < z_A < 1/2 < z_B < 1$ with or without information sharing. We show below that this condition holds if $v < t$. In the following, we consider only the case where the $\tau = 2$ outcome is interior duopoly. But the proposition holds for all other $\tau = 2$ outcomes, and the proof is available from the authors.

<u>The subgame without information sharing</u>

We solve the game backwards, starting with $\tau = 2$. Competition on $[z_A, z_B]$ is à la Hotelling, leading to the following prices and the location of the marginal consumer from this segment:

$$p_A^{2*} = \frac{(1-4z_A+2z_B)t}{3}, \quad p_B^{2*} = \frac{(-1-2z_A+4z_B)t}{3}, \quad x^* = \frac{1+2(z_A+z_B)}{6}.$$

For $[z_A, z_B]$ to be fully covered in $\tau = 2$, the net utility of consumer x^* must be positive. That is,

$$v - tx^* - p_A^{2*} = v - \frac{(1-2z_A+2z_B)t}{2} > 0. \qquad (6)$$

Profits from this segment are

$$\pi_A^{2c*} = \frac{(1-4z_A+2z_B)^2 t}{18}, \quad \pi_B^{2c*} = \frac{(-1-2z_A+4z_B)^2 t}{18}.$$

Consider next $[0, z_A]$ where firm A chooses personalized prices and $[z_B, 1]$ where firm B chooses personalized prices. Using p_A^{2*} and p_B^{2*}, we can derive the location of consumer $\tilde{x}_A$ whose net utility is zero if she chooses firm B and pays price p_B^{2*}, and similarly, $\tilde{x}_B$ whose net utility is zero if she chooses firm A and pays price p_A^{2*}:

$$\tilde{x}_A = \frac{2(1-z_A+2z_B)t - 3v}{3t}, \quad \tilde{x}_B = \frac{3v - (1-4z_A+2z_B)t}{3t}.$$

Then firm A chooses personalized price $v - tx$ for consumer $x \in [0, \tilde{x}_A]$ and $t(1-2x) + p_B^{2*}$ for consumer $x \in (\tilde{x}_A, z_A]$. Similarly, firm B chooses personalized price $v - t(1-x)$ for consumer $x \in [\tilde{x}_B, 1]$ and $t(2x-1) + p_A^{2*}$ for consumer $x \in [z_B, \tilde{x}_B)$. Then profits from these segments can be calculated as

$$\begin{aligned}
\pi_A^{2t*} &= \frac{2(-17z_A^2 + 10(1+2z_B)z_A - 2(1+2z_B)^2)t^2 + 12(1-z_A+2z_B)tv - 9v^2}{18t}, \\
\pi_B^{2t*} &= \frac{2(-17z_B^2 + 4(1+5z_A)z_B - (5-4z_A+8z_A^2))t^2 + 12(2-2z_A+z_B)tv - 9v^2}{18t}.
\end{aligned}$$

Because the above personalized prices cannot result in negative net utility for consumers z_A and z_B, we must have

$$v - t(1-z_A) - p_B^{2*} > 0 \quad and \quad v - tz_B - p_A^{2*} > 0. \tag{7}$$

Consider now $\tau = 1$. Given $\delta_c = 0$, we have $z_A = (v - p_A^1)/t$ and $z_B = (t - v + p_B^1)/t$. Thus, total profits for the two firms are $\Pi_{An} = p_A^1 z_A + \delta_f(\pi_A^{2t*} + \pi_A^{2c*})$ and $\Pi_{Bn} = p_B^1(1-z_B) + \delta_f(\pi_B^{2t*} + \pi_B^{2c*})$. Solving the first-order conditions for profit maximization gives us

$$p_A^{1*} = p_B^{1*} = \frac{3((1+4\delta_f)v - 2\delta_f t)}{6+10\delta_f}, \quad z_A^* = 1 - z_B^* = \frac{(3-2\delta_f)v + 6\delta_f t}{2(3+5\delta_f)t}.$$

From this, we can verify $z_A^* < 1/2 < z_B^*$ for any $v < t$. The resulting total profits are

$$\Pi_{An}^* = \Pi_{Bn}^* = \frac{(3+\delta_f)(3-2\delta_f(9+11\delta_f))v^2 + 72\delta_f(1+\delta_f)(2+\delta_f)vt - 18\delta_f(1+\delta)(3+\delta_f)t^2}{4(3+5\delta_f)^2 t}.$$

For the above equilibrium to be possible, we need conditions (6) and (7). One can verify that these two conditions are satisfied if and only if

$$v > \frac{(3+\delta_f)t}{2(2+\delta_f)} \equiv v_n. \tag{8}$$

The subgame with information sharing

The analysis is similar to the subgame without information sharing except one difference that, in $\tau = 2$, competition on $[0, z_A]$ and $[z_B, 1]$ is more intense because firms choose zero personalized price for consumers they cannot serve. Thus, we omit the details and only state total equilibrium profits and the condition needed to support the equilibrium, similar to the condition in (8).

Total equilibrium profits with information sharing are given by

$$\Pi^*_{As} = \Pi^*_{Bs} = \frac{(9 - 15\delta_f + 12\delta_f^2 - 2\delta_f^3)v^2 + 2\delta_f(9 - 2\delta_f)(1 - \delta_f)vt + \delta_f^2(5 - \delta_f)t^2}{4(3 - \delta_f)^2 t},$$

which is supported if and only if

$$v > \frac{(9 - \delta_f)t}{2(6 - \delta_f)} \equiv v_s. \tag{9}$$

Equilibrium of the information sharing game

We compare profits, Π^*_{in} and Π^*_{is} for $i = A, B$. Given that firms have the same profits, we only compare Π^*_{An} and Π^*_{As}. Direct calculation gives us

$$\begin{aligned} \Delta\Pi^*(v) \equiv \Pi^*_{An} - \Pi^*_{As} = & \frac{-4\delta_f(162 + 81\delta_f - 72\delta_f^2 + 48\delta_f^3 - 7\delta_f^4)v^2}{4(3 - \delta_f)^2(3 + 5\delta_f)^2 t} \\ & + \frac{2\delta_f(567 + 369\delta_f - 165\delta_f^2 + 107\delta_f^3 - 14\delta_f^4)vt}{4(3 - \delta_f)^2(3 + 5\delta_f)^2 t} \\ & - \frac{(486 + 369\delta_f - 75\delta_f^2 + 59\delta_f^3 - 7\delta_f^4)}{4(3 - \delta_f)^2(3 + 5\delta_f)^2 t}. \end{aligned}$$

We need conditions (8), (9), and $v < t$, hence $\max\{v_n, v_s\} < v < t$. First, notice that $\Delta\Pi^*(v)$ is strictly concave in v. Second, we can verify $\Delta\Pi^*(v)|_{v=\max\{v_n,v_s\}} > 0$ and $\Delta\Pi^*(v)|_{v=t} > 0$. This shows $\Delta\Pi(v) > 0$ for all v that satisfies $\max\{v_n, v_s\} < v < t$ because $\Delta\Pi^*(v)$ is strictly concave. Thus firms choose not to share information. ∎

Proof of Proposition 5: The subgame following the information sharing agreement has the same outcome as the case with perfectly correlated preferences. Thus, each firm earns the discounted sum of profits equal to $t/2 + \delta_f(t/4)$. In the following, we solve for the equilibrium of the subgame without information sharing.

We start with $\tau = 2$. Let z be the marginal consumer in $\tau = 1$. We will call $\mathcal{A} = [0, z]$, firm A's turf and $\mathcal{B} = [z, 1]$, firm B's turf. First, consider firm A's turf. Firm B anticipates that firm A can offer zero personalized prices to protect its turf. Thus the marginal consumer on $[0, z]$ given firm B's uniform price p_B^2 is $x_A = (t + p_B^2)/(2t)$. Then the demand facing firm B is

$$d_B^2 = \begin{cases} z\eta(1 - x_A) + (1 - \eta)(z - x_A) & \text{if } x_A < z \text{ and } z > 1/2, \\ z\eta(1 - x_A) & \text{if } x_A \geq z \text{ or } z \leq 1/2. \end{cases}$$

Firm B chooses p_B^2 to maximize its profit from $\mathcal{A}$ given by $\pi_{B,\mathcal{A}}^2 = p_B^2 d_B^2$. Solving the maximization problem, we have

$$p_B^{2*} = \begin{cases} \dfrac{t}{2} & \text{if } z \leq \dfrac{1}{2} \text{ or } \eta > \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \\ \dfrac{((2-\eta)z - (1-\eta))t}{2(1-\eta+\eta z)} & \text{if } z \geq \dfrac{3}{4} \text{ or } \eta \leq \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \end{cases}$$

$$x_A^* = \begin{cases} \dfrac{3}{4} & \text{if } z \leq \dfrac{1}{2} \text{ or } \eta > \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \\ \dfrac{(2+\eta)z + (1-\eta)}{4(1-\eta+\eta z)} & \text{if } z \geq \dfrac{3}{4} \text{ or } \eta \leq \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \end{cases}$$

$$\pi_{B,\mathcal{A}}^{2*} = \begin{cases} \dfrac{t\eta z}{8} & \text{if } z \leq \dfrac{1}{2} \text{ or } \eta > \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \\ \dfrac{((2-\eta)z - (1-\eta))^2 t}{8(1-\eta+\eta z)} & \text{if } z \geq \dfrac{3}{4} \text{ or } \eta \leq \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4). \end{cases}$$

Then, firm A chooses its personalized price, $p_A(x) = p_B^{2*} + t(1-2x)$ for $x \leq x_A^*$. Thus firm A's profit from $\mathcal{A}$ is

$$\pi_{A,\mathcal{A}}^{2*} = \begin{cases} \dfrac{z(3(8-5\eta) - 16(1-\eta)z)t}{16} & \text{if } z \leq \dfrac{1}{2} \text{ or } \eta > \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4), \\ \dfrac{((2+\eta)z + (1-\eta))^2 t}{16(1-\eta+\eta z)} & \text{if } z \geq \dfrac{3}{4} \text{ or } \eta \leq \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/2, 3/4). \end{cases}$$

Next, consider firm B's turf, $\mathcal{B}$. Following similar steps, we find that firm A faces demand

$$d_A^2 = \begin{cases} (1-z)\eta x_B + (1-\eta)(x_B - z) & \text{if } x_B > z \text{ and } z < 1/2, \\ (1-z)\eta x_B & \text{if } x_B \geq z \text{ or } z \geq 1/2 \end{cases}$$

where x_B is the marginal consumer's location in $\mathcal{B}$. Solving firm A's profit maximization problem, we obtain

$$p_A^{2*} = \begin{cases} \dfrac{t}{2} & \text{if } z \geq \dfrac{1}{2} \text{ or } \eta > \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \\ \dfrac{(1-2z+\eta z)t}{2(1-\eta z)} & \text{if } z \leq \dfrac{1}{4} \text{ or } \eta \leq \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \end{cases}$$

$$x_B^* = \begin{cases} \dfrac{1}{4} & \text{if } z \leq \dfrac{1}{2} \text{ or } \eta > \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/4, 1/2), \\ \dfrac{1+2z-3\eta z}{4(1-\eta z)} & \text{if } z \geq \dfrac{3}{4} \text{ or } \eta \leq \dfrac{(1-2z)^2}{1-z} \text{ for } z \in (1/4, 1/2), \end{cases}$$

$$\pi_{A,\mathcal{B}}^{2*} = \begin{cases} \dfrac{t(1-z)\eta}{8} & \text{if } z \geq \dfrac{1}{2} \text{ or } \eta > \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \\ \dfrac{(1-2z+\eta z)^2 t}{8(1-\eta z)} & \text{if } z \leq \dfrac{1}{4} \text{ or } \eta \leq \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \end{cases}$$

Given the above, firm B chooses its personalized price, $p_B(x) = p_A^{2*} - t(1-2x)$ for $x \geq x_B^*$, and earns profit from $\mathcal{B}$ given by

$$\pi_{B,\mathcal{B}}^{2*} = \begin{cases} \dfrac{t(1-z)(8+\eta+16(1-\eta)z}{16} & \text{if } z \geq \dfrac{1}{2} \text{ or } \eta > \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \\ \dfrac{(3-2z-\eta z)^2 t}{16(1-\eta z)} & \text{if } z \leq \dfrac{1}{4} \text{ or } \eta \leq \dfrac{(2z-1)^2}{z} \text{ for } z \in (1/4, 1/2), \end{cases}$$

Based on the above, we can divide possible $\tau = 2$ outcomes into three cases: Combining the two discussions, we classify the outcomes into the three cases: (i) $z < (4+\eta-\sqrt{\eta(8+\eta)})/8$; (ii) $(4+\eta-\sqrt{\eta(8+\eta)})/8 \leq z \leq (4-\eta+\sqrt{\eta(8+\eta)})/8$; (iii) $(4-\eta+\sqrt{\eta(8+\eta)})/8 < z$. Cases (i) and (iii) can result in asymmetric equilibria while case (ii) can lead to a symmetric equilibrium.

Consider now $\tau = 1$. Since $\delta_c = 0$, the marginal consumer's location is given by $z = (t - p_A^1 + p_B^1)/(2t)$. Then firm A chooses p_A^1 to maximize $\Pi_A = p_A^1 z + \delta_f(\pi_{A,\mathcal{A}}^{2*} + \pi_{A,\mathcal{B}}^{2*})$, and firm B chooses p_B^1 to maximize $\Pi_B = p_B^1(1-z) + \delta_f(\pi_{B,\mathcal{A}}^{2*} + \pi_{B,\mathcal{B}}^{2*})$. We proceed as follows. First, we focus on case (ii) and solve for each firm's local optimum. This gives us a symmetric candidate equilibrium where

$$p_A^1 = p_B^1 = t - \frac{\delta_f(8-\eta)t}{16}, \quad \Pi_A = \Pi_B = \frac{t}{2} + \frac{\delta_f(2-\eta)t}{8}.$$

Next, we check if either firm has incentives to deviate by choosing price that leads to cases (i) or (iii). One can verify that no firm has incentives to deviate.

Comparing the above profits with the profits under information sharing, $t/2 + \delta_f(t/4)$, we can conclude that both firms prefer information sharing to no information sharing. ∎

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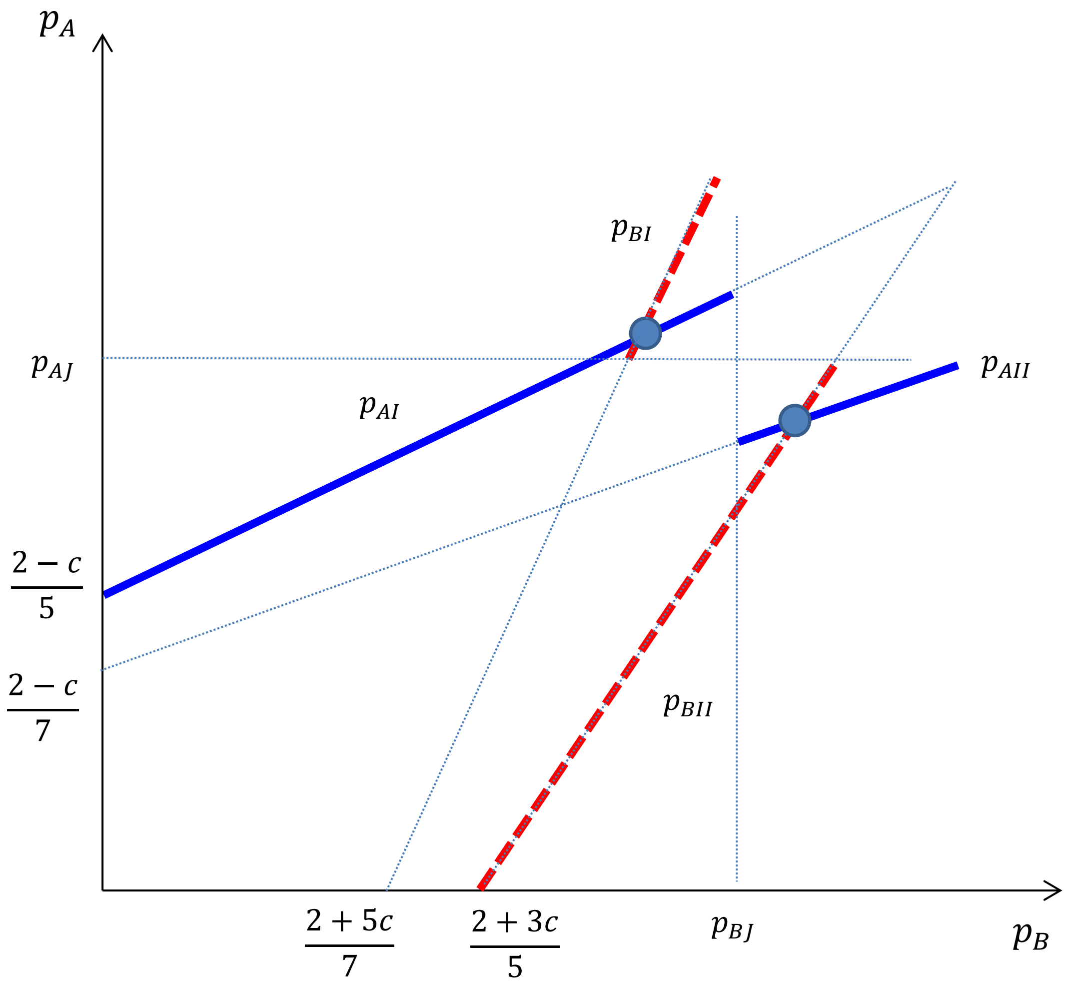

Figure 1: First-period multiple equilibria when $c \leq k$

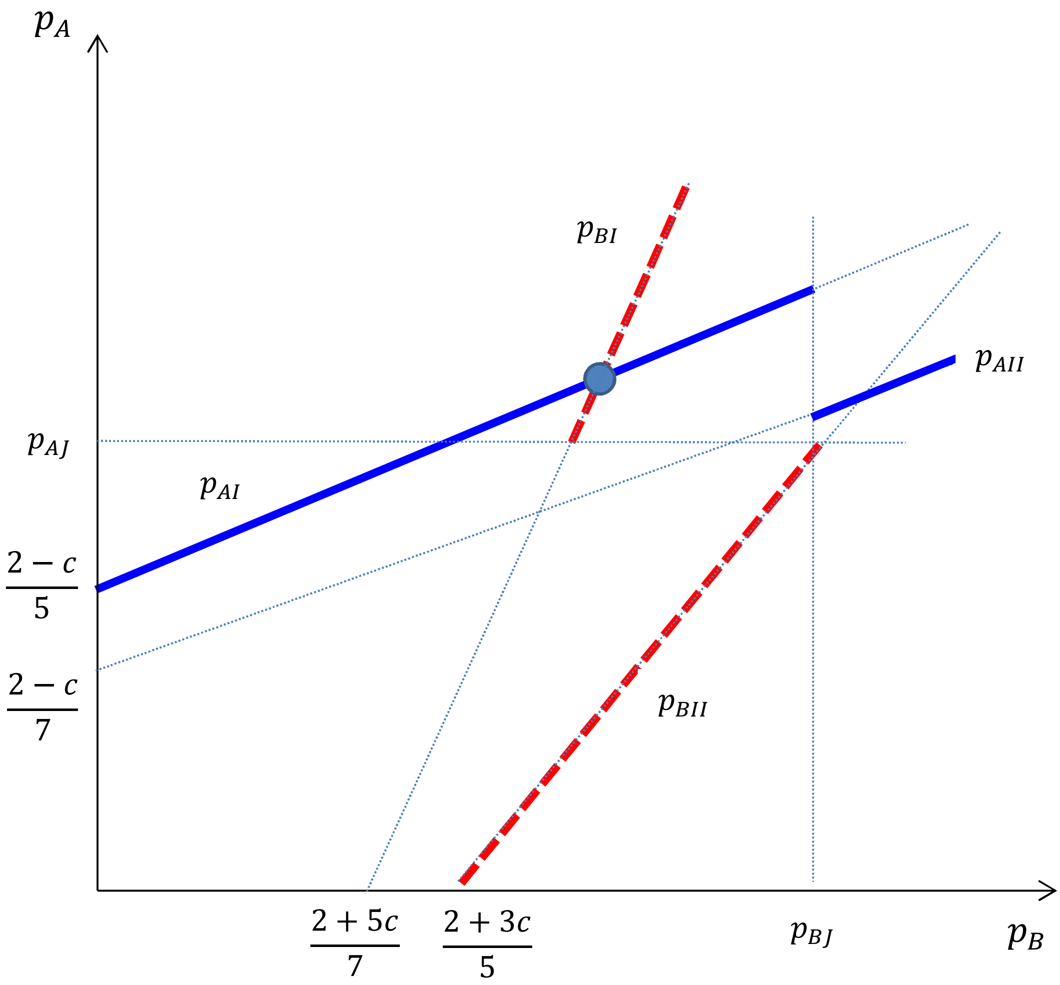

Figure 2: First-period unique equilibrium when $c > k$