Behavior-based algorithmic pricing

Journal Article

Author(s):
Dubus, Antoine

Publication date:
2024-03

Permanent link:
https://doi.org/https://doi.org/10.3929/ethz-b-000666173

Originally published in:
Information Economics and Policy 66, https://doi.org/10.1016/j.infoecopol.2024.101081

Information Economics and Policy 66 (2024) 101081

Contents lists available at ScienceDirect

Information Economics and Policy

journal homepage: www.elsevier.com/locate/iep

Behavior-based algorithmic pricing ☆

Antoine Dubus

Department of Management, Technology and Economics, ETH Zürich Leonhardstrasse 21 Switzerland, 8092 Zürich, Switzerland

ARTICLE INFO

Keywords:
Algorithmic pricing
Data collection
Behavior-based price discrimination

ABSTRACT

This article studies the impact of algorithmic pricing on market competition when firms collect data to charge personalized prices to their past customers. Pricing algorithms offer to each firm a rich set of pricing strategies combining first and third-degree price discrimination: they can choose for each of their past customers whether to charge them personalized or homogeneous prices. The optimal targeting strategy of each firm consists in charging personalized prices to past customers with the highest willingness to pay and a homogeneous price to the remaining consumers, including past customers with a low valuation on whom a firm has information. This targeting strategy maximizes rent extraction while softening competition between firms compared to classical models where firms target all past customers. In turn, price-undercutting and poaching practices are not sustainable with behavior-based algorithmic pricing, resulting in greater industry profits.

1. Introduction

With the advances in information technologies, companies are developing sophisticated pricing strategies based on the large amounts of data that they collect on their customers (Hinz et al., 2011; DalleMule and Davenport, 2017). Firms have now their data-management functions and chief data officers, and they are increasingly using practices of behavior-based price discrimination (BBPD), under which they collect data on their customers to propose them personalized offers and prices. Practices of BBPD are especially becoming common on the Internet (Gorodnichenko et al., 2018), where a firm such as Amazon can collect data on search behavior, GPS localization, and any type of personal information to feed machine-learning algorithms to personalize ads, products, and prices to the needs of its customers (Shiller et al., 2013). Recent studies document practices of BBPD in various industries such as newspapers (Asplund et al., 2008), credit markets (Ioannidou and Ongena, 2010) and mortgage markets (Thiel, 2019) among many others.

The economic literature has for long analyzed the impact of BBPD on the pricing strategies of competing firms and on consumer surplus (Fudenberg and Tirole, 2000; Acquisti and Varian, 2005; Fudenberg and Villas-Boas, 2006; Choe et al., 2018).[1] Yet, this stream of research is in general mute about the implementation of BBPD by firms. In practice, the widespread adoption of algorithmic techniques has transformed the way companies use consumer data and design their pricing strategies (Calvano et al., 2020; Wang et al., 2022; Peiseler et al., 2022), and provides a realistic way for firms to engage into practices of BBPD. Firms using pricing algorithms can combine techniques of first and third-degree price discrimination to enhance their profits (McSweeny and O'Dea, 2017; Gautier et al., 2020): they can choose for each past customer whether to charge a personalized price or to use a flexible third-degree price discrimination by pooling different consumers who are charged homogeneous prices.

Another essential property of pricing algorithms is that they can be used by firms to commit to a pricing strategy. The impact of this commitment is indeed the topic of a growing literature that shows how supra-competitive prices can be charged by firms when they adopt pricing algorithms (Salcedo, 2015; Klein, 2018; Bisceglia and Padilla, 2023; Brown and MacKay, 2023; Loots and den Boer, 2023).

This article embeds these two new elements in a model of behavior-based algorithmic pricing, to analyze how the ability for firms to target past customers strategically shapes their decision to collect consumer data, and impacts the competitive structure of data-driven industries. By doing so, it shows that classical results of the BBPD literature do not

☆ I am grateful to Roman Dolecek, Patrick Legros and Patrick Waelbroeck for useful remarks and suggestions. Part of this research was led as I was receiving financial support from the FNRS Grant PDR T.01.47.19. A previous version of this work has circulated under the title "Behavior-Based Price Discrimination with endogenous data collection and strategic customer targeting".

E-mail address: antoine1dubus@gmail.com.

[1] See also Chen and Pearcy (2010) who allow firms to reward loyal consumers, and Esteves et al. (2022) who consider general distributions of consumer preferences.

https://doi.org/10.1016/j.infoecopol.2024.101081
Received 25 September 2023; Received in revised form 1 February 2024; Accepted 5 February 2024
Available online 7 February 2024

hold anymore when firms can commit to their pricing strategy: firms do not compete to acquire consumer information, and a consumer always purchases products from the same brand. Moreover, this article provides new theoretical evidence on the anti-competitive impact of pricing algorithms. It also derives important recommendations for companies willing to exploit at best the potential of their customer data bases, now that they have access to efficient algorithms that allow them to fine-tune their pricing strategies.

The analysis considers a theoretical framework where competing firms collect data on their consumers, and then use an algorithm to design their pricing strategy. It builds on the flexible model of Choe et al. (2018), who consider a two-period competition framework à la Fudenberg and Tirole (2000). In the first period, firms have no information on their customers and charge a homogeneous price to the whole market. At the end of the first period, each firm can perfectly learn the willingness to pay of its customers for its product. In the second period of the framework of Choe et al. (2018), and in line with the literature, each firm uses all available information to price discriminate past customers.

Yet, using all available information may not be profit-maximizing for a firm, as information has two opposite effects on its profits. On the one hand, targeting consumers increases the profit of a firm through a better extraction of consumer surplus. On the other hand, information also intensifies competition, which reduces the profits of both firms. Indeed, when both firms target all their past customers, they price aggressively to poach consumers located far away from their locations. This increases the intensity of competition between firms and limits their ability to extract surplus from targeted consumers (Thisse and Vives, 1988).

In terms of modeling, the novelty of this article is to introduce pricing algorithms allowing firms to choose among a rich set of pricing strategies in the second competition period: a firm that has information on a group of past customers can choose to which consumers among this group it charges personalized prices or homogeneous prices. Such strategic targeting allows a firm to commit to a price structure that maximizes the surplus-extraction effect of information while softening its competitive effect. To the best of my knowledge, new practices of information design by firms using pricing algorithms have not yet been analyzed by previous literature, neither have their implications for firms and consumers.

Using this framework, I characterize the optimal strategy of a firm, which consists in targeting consumers with the highest willingness to pay for its product, and to charge a homogeneous price to a large share of low-valuation consumers – including past customers on whom the firm has collected data – to soften the intensity of competition. Hence, in equilibrium, firms do not use all available information, but charge personalized prices only to high-valuation consumers.

Central to the design of a targeting strategy is the ability of firms to commit to their strategy, and for this reason, this article also contributes to the literature on firms' commitment not to price discriminate consumers. While there are clear benefits from charging uniform prices to all customers and softening the intensity of competition between firms, the literature has also highlighted the difficulties of implementing such commitment. As Corts (1998) argues, even when competing firms can commit not to price discriminate consumers "the prisoner's-dilemma nature of the payoffs [...] dictates a unique equilibrium in which both firms discriminate" (p. 319). Indeed in our framework, a firm that targets either all past customers or charges them a uniform price has a unilateral incentive to price discriminate all customers and will never commit to charge uniform prices. Conversely, we will see that a firm that has access to a rich set of pricing strategies but that cannot commit to them will also charge targeted prices to all consumers on whom it has information. With this respect, the analysis of Choe et al. (2018) corresponds to the case where a firm may develop a sophisticated targeting strategy, but cannot commit to it.

The literature has then analyzed under which conditions firms can escape the prisoners' dilemma. Corts (1998) provides conditions on firms' asymmetry for a commitment not to price discriminate to be sustainable. Liu and Serfes (2007) analyze infinitely repeated games where firms enter tacit collusion using tit-for-tat equilibrium strategies, and show that when the ability of firms to price discriminate consumers improves, tacit collusion becomes harder to sustain.[2] Acemoglu (2021) analyzes competition when one of the firms can use consumer data to improve product quality and charge consumers targeted prices. The author shows that when a single firm acquires data, it charges higher prices thanks to the ability to personalize products, and that its competitor can also raise its price, even when it remains uninformed. The present article contributes to this literature by showing that, in a static game with symmetric firms, strategic targeting provides firms with incentives to unilaterally commit not to use all consumer information. This effect takes place without product personalization and only through changes in the pricing strategies of the firms.

This new result has important implications for industries willing to implement strategic consumer targeting, and raises the question of how firms can credibly commit not to target all past customers. Besides allowing firms to design sophisticated pricing strategies, pricing algorithms also offer a simple way for firms to implement such a strategic commitment. The use of pricing algorithms as devices to commit a specific strategy is indeed the topic of a growing literature (Salcedo, 2015; Klein, 2018; Bisceglia and Padilla, 2023; Brown and MacKay, 2023; Loots and den Boer, 2023). In these models, the use of a pricing algorithm is observable by a firm's competitor and provides credible information on the ability of the firms to commit to a pricing strategy. Hence, a company that is transparent on the type of pricing algorithms that it uses sends a valuable signal to its competitors, which can be used as a commitment device to engage into strategic targeting.[3] For instance, Uber has publicly adopted route-based pricing techniques for the rides of its users,[4] and United Airlines and Delta have also made public their adoption of pricing algorithms for frequent users.[5] This result has important managerial implications, as it emphasizes the role of algorithmic pricing techniques on the sustainability of pricing strategies.

The remainder of this article is organized as follows. Section 2 describes the model. Section 3 characterizes the optimal targeting strategies of the firms, as well as the equilibrium in both competition periods. The case of forward-looking consumers who anticipate the targeting strategies of the firms is considered in Section 4. Section 5 concludes.

2. Description of the model

Two horizontally differentiated firms – Firm A and Firm B – compete in a product market. There are two competition periods $s = 1, 2$, in which firms sell non-durable goods.[6] In the first period, firms have no information on consumers and compete by setting homogeneous prices. Firms then learn the willingness to pay of each of their customers for their product, and in period 2, firms use a pricing algorithm allowing them to charge targeted prices to some of their past customers. Both firms incur the same marginal cost of production, which is normalized to zero, and in each period consumers have unit demands.

---

[2] Their results pioneers recent literature on tacit collusion in repeated games when firms adopt pricing algorithms (Calvano et al., 2020).

[3] Bertini and Koenigsberg (2021) also discusses how the adoption of algorithmic dynamic pricing can be used as a commitment to consumers to charge them fair prices, compared with "hand made" dynamic pricing.

[4] Is Uber Really Charging Frequent Users Higher Fares?; March 30, 2018.

[5] United follows Delta in bringing dynamic pricing model for loyalty program reward redemption, Corporate Travel Community, April 19, 2019.

[6] Other models also consider an infinite number of competition periods (Villas-Boas, 1999, 2004). The results of this article are not affected by these different timing structures, and we focus on a two-stage framework for simplicity.

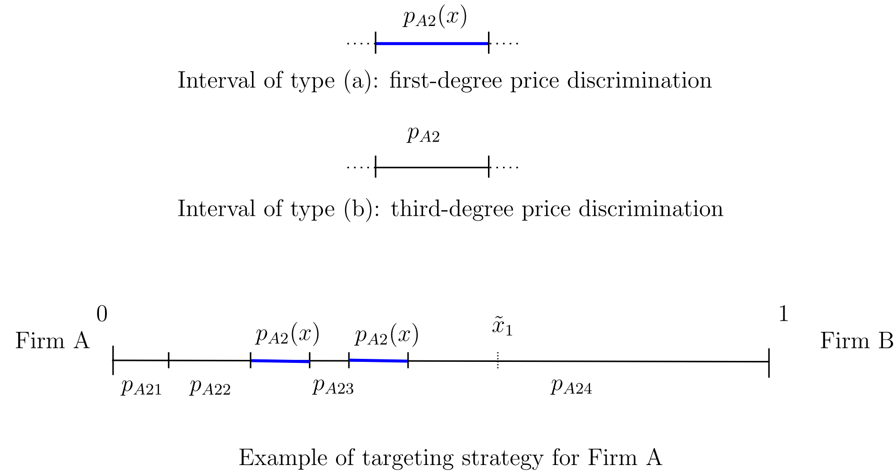

Fig. 1. Possible types of intervals when Firm A targets consumers strategically.

2.1. Consumers

Consumers are uniformly distributed on a unit line $[0, 1]$,[7] and in each period s they can buy one product at a price p_{As} from Firm A located at 0, or p_{Bs} from Firm B located at 1. Consumers located at $x \in [0, 1]$ derive a utility V from purchasing the product. They incur a transportation cost $t > 0$ so that buying from Firm A (resp. from Firm B), has a total cost tx (resp. $t(1-x)$). In each period, consumers purchase the product for which they have the highest utility, and in period 2, different consumers may pay different prices as firms know at this point the willingness to pay of their past customers.

In period $s = 1, 2$, consumers located at x have a utility function defined by:

$$u_s(x) = \begin{cases} V - p_{As} - tx, \text{ if they buy from Firm A,} \\ V - p_{Bs} - t(1-x), \text{ if they buy from Firm B.} \end{cases} \quad (1)$$

The market is assumed to be covered, which is a standard consideration of the literature (see for instance Thisse and Vives (1988), Liu and Serfes (2004), Stole (2007), Ulph and Vulkan (2000), Montes et al. (2019), and Bounie et al. (2021).) This implies that the product value to consumers satisfies $\frac{V}{2} \geq t$.[8]

Consumers are assumed to be myopic in the baseline model, and they maximize their utility at each consumption period.[9] Moreover, we assume that there is no cost to switch from one product to the other after the first period. While switching costs in BBPD models are the topic of intense research (Mehra et al., 2012), we will see that they do not impact the outcome in this framework, as even at no cost, switching will not occur in equilibrium.

2.2. Firms

This section describes the set of targeting strategies available to firms using pricing algorithms in the second period. It then provides the profits of the firms in each period of the game, as well as their objective functions.

Firms first compete in period 1 – the information acquisition period – in which each firm collects perfect information on its customers.[10] Let us denote by $\tilde{x}_1$ the consumer indifferent between buying from Firm A and Firm B in the first period, such that Firm A serves consumers on $[0, \tilde{x}_1]$ and Firm B serves consumers on $[\tilde{x}_1, 1]$.

2.2.1. Targeting strategies

In period 2 – the targeting period – firms use pricing algorithms that simultaneously choose which of their past customers they price-discriminate. By using these algorithms, firms publicly commit to their strategy, and they set prices accordingly.[11] A pricing algorithm allows firms to target two different types of intervals of the consumer demand[12]:

- (a) On the first type of intervals a firm charges personalized prices to all past customers.
- (b) A firm can charge a homogeneous price to customers in the second type of intervals.

Fig. 1 illustrates these two types of intervals for Firm A.

On intervals of type (a) (in blue) Firm A charges to each customer a personalized price $p_{A2}(x)$. Firm A charges a homogeneous price p_{A2i} to all consumers in the ith intervals of type (b) (starting from the left).

A pricing algorithm allows for any combination of type (a) and (b) intervals. For instance, the last line of Fig. 1 displays from the left to the right two type (b) intervals where Firm A charges respectively prices p_{A21} and p_{A22}. Then Firm A charges personalized prices to each consumer on an interval of type (a) represented in blue. Firm A then charges a homogeneous price p_{A23} to consumers in a third type (b) interval, personalized prices in a second (blue) type (a) interval, and finally, a homogeneous price p_{A24} for consumers on the rest of the line.

Remember that $\tilde{x}_1$ denotes the indifferent consumers in the first competition period, so that Firm A has no information on consumers located at the right of $\tilde{x}_1$ and must charge them a homogeneous price. In Fig. 1, these consumers are pooled with some consumers located to

[7] Uniform consumer distribution is a standard specification of the literature, whose limits have recently been discussed by Esteves et al. (2022).

[8] Indeed, market coverage requires that in a model without information, when a firm is a monopolist (Firm A w.l.o.g.) consumers at the extremity of the line (i.e. located at 1) derive a positive utility from consuming in equilibrium. In monopoly, the indifferent consumer satisfies $u(x) = V - tx - p_A = 0 \implies x = \frac{V - p_A}{t}$. The profits of the monopolist are equal to $\pi_A(p_A) = p_A \frac{V - p_A}{t} \implies p_A^* = \frac{V}{2}$. Consumers located at 1 purchase the product if $u(1) = \frac{V}{2} - t \geq 0 \implies \frac{V}{2} \geq t$.

[9] We relax this assumption by considering forward-looking consumers in Section 4.

[10] Choe et al. (2018) also adopt a model where data allows firms to perfectly learn the location of each customer that it serves. This specification is required for firms to have sophisticated targeting strategies, which is the focus of this article.

[11] We discuss in detail how firms can implement such commitment in practice Section 5.

[12] These possible targeting strategies are in line with recent literature on information design in models with horizontal differentiation (Bounie et al., 2021).

the left of $\tilde{x}_1$ even though Firm A has information about them, and they are charged price p_{A24}. Similarly, Firm B has no information on consumers located to the left of $\tilde{x}_1$ and also charges them a homogeneous price. A novel result of this analysis is that, in equilibrium, firms charge the same price to consumers on whom they have no information and to some of their past customers even though they have information about them, as doing so softens the intensity of competition.

In period 2, Firm A's pricing algorithm can use any potential combination of type (a) and type (b) intervals to maximize profits. Let us denote by $\Psi_A(\tilde{x}_1)$ the continuous set of all possible partitions of the unit line into type (a) and type (b) intervals. This set depends on the share of customers on whom Firm A has collected data in period 1: $[0, \tilde{x}_1]$. Similarly, Firm B can choose any partition in the set $\Psi_B(\tilde{x}_1)$ generated by the information it has on customers in $[\tilde{x}_1, 1]$.

When choosing its targeting strategy, the algorithm of Firm θ ($\theta = A, B$) selects the partition $\mathcal{X}_\theta \in \Psi_\theta(\tilde{x}_1)$ of consumers to price discriminate. For a given partition $\mathcal{X}_\theta$, let us denote by $\mathcal{X}_\theta^a$ the subset of type (a) segments, and by $\mathcal{X}_\theta^b$ the subset of type (b) segments, such that $\mathcal{X}_\theta = \mathcal{X}_\theta^a \cup \mathcal{X}_\theta^b$; $\mathcal{X}_\theta^a \cap \mathcal{X}_\theta^b = \emptyset$.

Note that this strategy space includes as special cases the models of Fudenberg and Tirole (2000) where firms charge a homogeneous price to all past customers and another price to customers of the competitors, and of Choe et al. (2018) where firms target all past customers, and Firm A uses only one type (a) interval on $[0, \tilde{x}_1]$ and similarly for Firm B on $[\tilde{x}_1, 1]$.

While previous literature has focused on firms that price-discriminate all consumers that they have identified, this article considers strategic targeting as using all available information may not be optimal for a firm. There are indeed two opposite effects of information on the profit of a firm. On the one hand, targeting consumers increases the profit of a firm through a better extraction of consumer surplus. On the other hand, information also increases competition, which reduces the profits of both firms. Indeed, when both firms target all their past customers, they price aggressively to poach consumers located far away from their locations. This increases the intensity of competition between firms and limits their ability to extract surplus from targeted consumers. Section 3.3.1 characterizes the optimal information structure for each firm, which balances these two effects of information on the profits of the firms.

2.2.2. Profits

Profits in period 1. This analysis focuses on Subgame Perfect Nash Equilibria.[13] At the beginning of period 1, firms only know that consumers are uniformly distributed on the unit line. The objective of Firm θ is to set a homogeneous price – denoted by $p_{\theta 1}$ and characterized in Section 3 – to maximize its total profits, composed of the sum of its profits in both periods by discounting period 2 with factor δ.[14] As is standard in Hotelling competition with uniform prices, the resulting demand can be written $d_{\theta 1} = \frac{p_{-\theta 1} - p_{\theta 1} + t}{2t}$, where $d_{A1} = \tilde{x}_1$ and $d_{B1} = 1 - \tilde{x}_1$. The profit of Firm θ in period 1 can be written $\pi_{\theta 1} = d_{\theta 1} p_{\theta 1}$.

Profits in period 2. In period 2, the pricing algorithms first determine the targeting strategies of the firms, and then firms charge prices accordingly. The targeting strategies are chosen as simultaneous best responses and we will show that they constitute the unique pure strategy equilibrium of the game. Hence, in period 1, firms anticipate the equilibrium of period 2 and charge prices $p_{\theta 1}$ and $p_{\theta 2}$ accordingly.

For a given partition $\mathcal{X}_\theta = \mathcal{X}_\theta^a \cup \mathcal{X}_\theta^b$ prices are set as follows. In the set $\mathcal{X}_\theta^a$, prices $p_{\theta 2}(x)$ are set as high as possible under the competitive constraint exerted by Firm $-\theta$.[15] Firm θ charges homogeneous prices $p_{\theta 2i}$ on each segment in $\mathcal{X}_\theta^b$, with $i = 1, .., n$ and where n corresponds to the total number of segments in $\mathcal{X}_\theta^b$. In each segment in $\mathcal{X}_\theta^b$, prices $p_{\theta i2}$ yield corresponding demands $d_{\theta i2}$. Let us denote by $\mathbf{p}_{\theta 2} = (p_{\theta 12}, .., p_{\theta n2})$ the vector composed of all prices charged in the different segments of $\mathcal{X}_\theta^b$. In period 2, Firm θ sets prices in order to maximize the following profit function:

$$\pi_{\theta 2}(p_{\theta 2}(x), \mathbf{p}_{\theta 2}) = \int_{\mathcal{X}_\theta^a} p_{\theta 2}(x) dx + \sum_{i=1}^{n} p_{\theta i2} d_{\theta i2}. \tag{2}$$

Moreover, the two following specifications are adopted regarding the targeting and pricing decisions of the firms, as well as sequential pricing.

Sequential targeting and pricing decisions. The algorithms first choose their pricing strategies, and then firms implement them and charge prices. This timing is common in the literature on algorithmic pricing where firms first calibrate the properties of their algorithm, which then determines a pricing strategy based on the characteristics of the market and of competing firms among other (Hansen et al., 2021; Eschenbaum et al., 2022). It is also used in the theoretical literature on targeted advertising, where firms first choose to which consumers they send an ad, and then set prices accordingly (Anderson and Renault, 2009).

Our focus on this timing is also supported by managerial practices. As Du et al. (2021) emphasize, data analytics teams – in charge of the targeting strategy – and marketing decision-makers – in charge of setting prices – are frequently at arm's length in centralized organizations.

Sequential pricing. Considering the pricing decisions of the firms, it is necessary to compute demands and prices on each consumer segment to obtain the profits of the firms. When a firm has no information, it sets a uniform price on the whole interval $[0, 1]$. On the contrary, a firm that uses a partition $\mathcal{X}_\theta$ can personalize prices. For each consumer in $\mathcal{X}_\theta^a$, Firm θ will charge a personalized price as a monopolist constrained by the homogeneous price charged by Firm $-\theta$. In the set $\mathcal{X}_\theta^b$, after firms set their prices, there are two types of segments to analyze: segments on which both firms have a strictly positive demand, and segments on which Firm θ is a monopolist.

The model adopts the additional assumption that, after having charged prices on the different segments, each Firm θ can reset its prices on the segments where it is a monopolist. Hence, Firm θ first sets prices $p_{\theta i2}$ on all segments of $\mathcal{X}_\theta^b$, as well as prices $p_{\theta 2}(x)$ for targeted consumers. Then it resets the monopoly prices $p_{\theta 2}(x)$ for each targeted consumer in $\mathcal{X}_\theta^a$ to which it sells its product, and prices $p_{\theta i2}$ on the segments of $\mathcal{X}_\theta^b$ where Firm θ is a monopolist. Consumers observe prices and make their consumption decision after this price reset.

Sequential pricing decision is necessary to avoid the non-existence of Nash equilibrium in pure strategies. Consider indeed the case where Firm A sets prices simultaneously in two different segments – p_{A12} in segment 1 and p_{A22} in segment 2 – and Firm B charges a homogeneous price p_{B2}. The equilibrium prices p_{A12}, p_{A22}, and p_{B2} are chosen as simultaneous best responses. In the case where Firm A is a monopolist on segment 1, the price p_{A12} taken as the best response to p_{B2} is not profit maximizing: an increase in p_{A12} increases the profits of Firm A as long as Firm B does not reach a positive demand on the segments of p_{A12}. Let us denote $\hat{p}_{A12}$ this limit price. The situation where Firm A sets $\hat{p}_{A12}$ and Firm B charges p_{B2} is not an equilibrium either as Firm B has now an additional incentive to increase p_{B2} and reach a positive demand on both segments where Firm A charges $\hat{p}_{A12}$ and p_{A22}, and there is no

[13] The equilibrium concept is discussed in detail in Section 2.4.

[14] Considering a discounted future for the firms is in line with the literature (Fudenberg and Villas-Boas, 2006). The model includes the limit case where the second period is not discounted when $\delta = 1$.

[15] As firms have collected information on different consumers in the first stage (on $[0, \tilde{x}_1]$ for Firm A and on $[\tilde{x}_1, 1]$ for Firm B), the consumers that Firm θ can price discriminate are those on whom Firm $-\theta$ has no information.

Nash equilibrium in pure strategy in this case. Under sequential pricing, when firms reset their monopoly prices they do not change their competitive prices anymore, and the resulting prices constitute a pure strategy Nash equilibrium.

For this reason, the decision of firms to set prices in two stages is a standard consideration of the literature on price personalization. For instance, Choudhary et al. (2005), Jentzsch et al. (2013), Matsumura and Matsushima (2015), Chen et al. (2020), Belleflamme et al. (2020) and Bounie et al. (2021) focus on sequential pricing where a higher personalized price is charged to identified consumers after a firm sets a uniform price. We will see that in equilibrium, this assumption boils down to having firms set first their homogeneous prices, and then targeted prices for consumers that they price discriminate.

Sequential pricing is also common in managerial practices. Recently, Amazon has been accused of showing higher prices for Amazon Prime subscribers – who pay an annual fee for unlimited shipping services – than for non-subscribers (Lawsuit alleges Amazon charges Prime members for "free" shipping, Consumer affairs, August 29, 2017). Thus Amazon first sets a uniform price and then increases prices for high-valuation consumers who are better identified when they join the Prime program.

Objective functions of the firms. Demands in the information acquisition period have an impact on the targeting strategies of the firms in the targeting period. To emphasize the impact of prices in period 1 on market outcome in period 2, the location of the indifferent consumer can be written as a function of prices in period 1: $\tilde{x}_1(p_{A1}, p_{B1})$. Overall the objective functions of the firms at the beginning of the game are:

$$\begin{aligned}
&\text{For Firm A:} \quad \max_{p_{A1}} \{\pi_{A1}(p_{A1}, p_{B1}) + \delta \pi_{A2}(p_{A2}(x), \mathbf{p}_{A2}, \tilde{x}_1(p_{A1}, p_{B1}))\} \\
&\text{For Firm B:} \quad \max_{p_{B1}} \{\pi_{B1}(p_{B1}, p_{A1}) + \delta \pi_{B2}(p_{B2}(x), \mathbf{p}_{B2}, \tilde{x}_1(p_{A1}, p_{B1}))\}
\end{aligned} \tag{3}$$

2.3. Timing

This section summarizes the timing of the game. In period 1, firms compete and collect data on their customers. In period 2, the pricing algorithms choose the partitions $\mathcal{X}_A$ and $\mathcal{X}_B$ of consumers that they target. Then firms set prices on the different segments, and in the last stage, firms reset prices on their monopoly segments. The timing of the game is the following:

- Period 1:
  - Firms compete by setting prices p_{A1} and p_{B1} and learn the location of their customers on the unit line.
- Period 2:
  - Stage 1: Each Firm θ chooses the partition $\mathcal{X}_\theta$ of consumers to price-discriminate and publicly commits to this strategy.
  - Stage 2: Each Firm θ sets prices on the different segments of $\mathcal{X}_\theta$.
  - Stage 3: Firms reset prices $p_{\theta 2}(x)$ on consumers that they price-discriminate in $\mathcal{X}_\theta^a$, as well as prices on the monopoly segments of $\mathcal{X}_\theta^b$.
  - Stage 4: Consumers observe prices and make their consumption decisions.

It is important to stress that the choice of the targeting strategies may not necessarily take place after the first competition period, but could also take place at the very beginning of the game without changing the equilibrium outcome.[16] Indeed, in practice, firms do not reconsider their pricing algorithm at each period as doing so is usually costly, and many competition periods may unfold in which, at each of them, firms collect consumer data and target past consumers. The stability of the results to this alternative timing suggests that the insights from this analysis are robust when considering more (and even infinite) competition periods between firms.

2.4. Equilibrium concept

Throughout the analysis, the focus is on subgame perfect Nash equilibria. In period 1, firms anticipate that the information they collect on consumers can be used in period 2. Firms therefore set prices according to two different forces. On the one hand, they want to maximize profits in the first competition period. On the other hand, they may also want to serve a large consumer demand to achieve higher prices in period 2.[17]

At the beginning of period 2, the partitions $\mathcal{X}_A$ and $\mathcal{X}_B$ are chosen as simultaneous best responses constituting the unique pure strategy Nash equilibrium of this stage.

3. Analysis

To highlight the importance of commitment, we first consider the targeting strategies in equilibrium when firms cannot commit. The game when firms have access to a commitment device is then solved. As usual, the analysis proceeds backward. First, the optimal targeting strategies of firms in the second period are characterized in Section 3.3. Section 3.4 analyzes competition in period 1 and information acquisition by firms.

3.1. Equilibrium without commitment

Firms use all information if they cannot commit to a targeting strategy. Consider Firm A (without loss of generality) that has collected information on consumers in the first competition period, and willing to choose a targeting strategy for the second competition period. The information set from which it chooses the consumers to price discriminate is $\Psi_A(\tilde{x}_1)$ with $\tilde{x}_1$ taken as exogenous throughout this section. Firm A does not use all available information if the set $\mathcal{X}_A^a$ does not cover all consumers: $\mathcal{X}_A^a \neq \Psi_A(\tilde{x}_1)$, and there are consumers for which Firm A has information, but that it does not price discriminate at the first degree. Doing so may be interesting for Firm A if Firm B can observe this targeting strategy and increase its homogeneous price on $[0, \tilde{x}_1]$. In this case, competition for consumers close to Firm A is relaxed, enhancing the potential for rent-extraction.

Now, if Firm A cannot commit to a targeting strategy, once Firm B has set its higher price on $[0, \tilde{x}_1]$, Firm A has interest to change its targeting strategy and price discriminate all consumers at the first degree. This deviation is profitable as it allows Firm A to extract more surplus from consumers who were initially not targeted. Firm B anticipates this reaction and charges a low homogeneous price on $[0, \tilde{x}_1]$. The equilibrium best response of each firm is therefore to target all past consumers, as in previous literature.

Hence, for each firm to have interest not to use all available information, it is necessary that firms can commit to their targeting strategy, and that the following prices are set according to the strategies of both firms. When a firm cannot commit to a targeting strategy, it has interest to target all customers and engage into all-out competition (Corts, 1998).

Firms compete more fiercely when they cannot commit. When firms charge personalized prices to all consumers, they make the following profits for a given value of $\tilde{x}_1$[18]:

[16] I would like to thank a referee for pointing out this alternative timing.

[17] The contribution of this article will be to show that, contrary to previous literature, when firms target consumers strategically in period 2, they do not fight for information acquisition in period 1. Hence firms set prices in period 1 only accounting for their present profits, and competition is identical to the standard Hotelling framework.

[18] Appendix A.2 explains how to obtain these values.

$$\pi_{A2} = \frac{t}{2} - \frac{7}{9}\tilde{x}_1^2 t + \frac{2}{9}(1-\tilde{x}_1)^2 t - \frac{4}{9}\tilde{x}_1(1-\tilde{x}_1)t + \frac{2}{3}\tilde{x}_1 t - \frac{2}{3}(1-\tilde{x}_1)t,$$
$$\pi_{B2} = \frac{t}{2} - \frac{7}{9}(1-\tilde{x}_1)^2 t + \frac{2}{9}\tilde{x}_1^2 t - \frac{4}{9}(1-\tilde{x}_1)\tilde{x}_1 t + \frac{2}{3}(1-\tilde{x}_1)t - \frac{2}{3}\tilde{x}_1 t.$$

Simple comparison shows that the sum of these profits is lower than t, the industry profits in the Hotelling model without information. Hence, targeting all consumers lowers the profits of the firms, and we will see in the next section that, when firms can commit, the optimal targeting strategies leave a large share of un-targeted consumers in the middle of the line to soften the intensity of competition.

We can hint at the impact of targeting without commitment on the first competition period using the results of Choe et al. (2018).[19] Indeed, they show that, as the profits of the firms in the second period crucially depend on the location of the indifferent consumers in the first period $\tilde{x}_1$, firms are ready to lower their prices in period 1. Doing so allows a firm to charge personalized prices to more consumers and extract their surplus. Hence, a central result of Choe et al. (2018) is that firms will charge prices below those in the Hotelling model without information, and will achieve lower profits.

More precisely, one of the firms will set aggressive prices in the first period and sell to consumers located close to its competitor, while the competitor will serve a small share of the consumer demand. In turn, the firm with the greatest demand in period 1 obtains a strong data advantage that it uses to charge personalized prices to a large share of the demand in period 2. The unique type of equilibrium in this case is asymmetric, as firms compete fiercely to acquire consumer information.

Overall, industry profits are lower, and consumer surplus is greater when firms cannot commit to a targeting strategy than when they have access to a commitment device. An important contribution of this article is to show that, when firms can commit, they do not compete for information in the first period and charge the standard Hotelling prices, above those in Choe et al. (2018). In turn, as we will see that firms use only part of the collected data in the second stage, they also compete less fiercely. Hence, we will see that pricing algorithms allow firms to increase their profits and have a negative impact on consumer surplus at both competition periods.

3.2. Equilibrium with commitment

This section first characterizes the general properties of the information structure in equilibrium. Firms target only part of their past customers:

- Each firm charges personalized prices to high-valuation consumers.
- Remaining consumers are untargeted, including low-valuation customers on whom firms have information.

Then I characterize the pricing decision of the firms when they use these information structures in the second stage, depending on the number of consumers on whom they have collected information. Finally, I analyze how the use of information in the second period impacts the pricing decisions of the firms in the first period. I show that, because firms only use information on their closest consumers, they do not fight to acquire information on consumers located in the middle of the line, and competition is identical to the classical Hotelling model. Comparing both competition periods, I show that the unique equilibrium of the game is symmetric, and firms do not engage in consumer poaching during the targeting period.

[19] They focus on quadratic transportation costs, so that we cannot compare the equilibrium prices and profits, but we use their qualitative insights to better understand the impact of commitment when transportation costs are linear.

3.3. Period 2: strategic targeting

This section characterizes the optimal targeting strategies determined by the pricing algorithms of the firms in period 2 when they can price discriminate their past customers. It shows that strategic firms optimally target close-by consumers with the highest willingness to pay for their products and charge a homogeneous price to all remaining consumers, including some consumers on whom they have information. Such information structure maximizes surplus extraction from consumers with the highest willingness to pay while softening the competitive effect of information.

3.3.1. Optimal information structure

In period 2 the firms use pricing algorithms to choose the partitions $\mathcal{X}_A$ and $\mathcal{X}_B$ of past customers that each firm price-discriminates. Proposition 1 characterizes the optimal partitions.

Proposition 1. *There exist $x_A \in [0, \tilde{x}_1]$ & $x_B \in [0, 1-\tilde{x}_1]$ such that in equilibrium:*

- *Firm A targets all consumers on $[0, x_A]$ and charges a homogeneous price on consumers on $[x_A, 1]$.*
- *Firm B targets all consumers on $[1-x_B, 1]$ and charges a homogeneous price on consumers on $[0, 1-x_B]$.*

Proof. See Appendix A.1.

The proof proceeds in the following way. Considering any information structure for each firm, it shows that, for any targeting strategy adopted by Firm B, Firm A finds it profitable to re-order segments so that Firm A first-degree price discriminates consumers closest to its location, and charges a homogeneous price to the rest of the unit line. Focusing on close-by consumers allows Firm A to extract surplus from customers with the highest willingness to pay, while limiting the competitive effect of information by leaving a large share of consumers who are charged a homogeneous price. Applying this reasoning to Firm B allows us to show that it also has interest to first-degree price discriminate close-by consumers only.

Proposition 1 is a central result of this article and makes an important contribution to the literature, where firms cannot commit to a targeting strategy and use all available consumer information. When firms can commit to a targeting strategy, an optimal information partition maximizes the profit of a firm by dividing the unit line into two intervals. Firm A charges targeted prices to consumers in the first interval on $\mathcal{X}_A^a = [0, x_A]$, which is referred to as the share of targeted consumers, who have the highest willingness to pay for Firm A's product. Firm A does not target consumers on $\mathcal{X}_A^b = [x_A, 1]$ – with a lower willingness to pay –, and charges a uniform price on this second interval, referred to as the share of untargeted consumers. Similarly, Firm B optimally targets high-valuation consumers belonging to $\mathcal{X}_B^a = [1-x_B, 1]$ and charges a homogeneous price to low-valuation consumers on $\mathcal{X}_B^b = [0, 1-x_B]$. Consumers on $[x_A, 1-x_B]$ are targeted by none of the firms in period 2. By leaving a share of consumers untargeted by firms, these optimal targeting strategies balance the rent extraction and the competition effects of information.[20]

Fig. 2 illustrates the targeting strategies of Firm A and Firm B. The thick lines represent consumers who are targeted by Firm A on $[0, x_A]$, and by Firm B on $[1-x_B, 1]$. Consumers on segments $[x_A, 1]$ and $[0, 1-x_B]$ are charged a homogeneous price by Firm A and Firm B respectively. Fig. 2 also displays $\tilde{x}_1$, the location of the indifferent consumer in period 1.

[20] Proposition 1 also generalizes the results of Bounie et al. (2021) by characterizing the optimal targeting strategies of firms using first-party data.

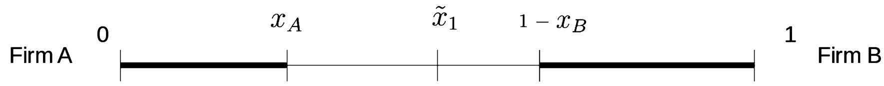

Fig. 2. Targeting strategies of firms in period 2.

Our focus in the first stage of period 2 is on pure strategy Nash equilibria when firms can commit to their targeting strategy, characterized by the (unique) equilibrium values of x_A and x_B. As it is assumed that firms choose x_A and x_B simultaneously, their equilibrium values will be derived by computing x_A as a simultaneous best response to x_B and reciprocally.

Lee et al. (2011) have been the first ones to consider the possibility for firms to use such information partitions to price discriminate consumers, analyzing competition for exogenous values of x_A and x_B and focusing on consumer privacy.[21] The present article contributes to their analysis by formally characterizing the optimal information partitions chosen by firms using collected data, and by providing a proof of the optimality of these information structures.

Profits in period 2. In period 2, each firm charges personalized prices $p_{\theta 2}(x)$ to targeted consumers and charges price $p_{\theta 2}$ on the rest of the unit line. Prices $p_{\theta 2}(x)$ are set as high as possible under the competitive constraint exerted by price $p_{-\theta 2}$. Hence, firms set prices in period 2 in order to maximize the following profit functions:

$$\pi_{A2}(p_{A2}(x), p_{A2}) = \int_0^{x_A} p_{A2}(x)dx + p_{A2}d_{A2},$$
$$\pi_{B2}(p_{B2}(x), p_{B2}) = \int_{1-x_B}^{1} p_{B2}(x)dx + p_{B2}d_{B2}. \tag{4}$$

Strategic interaction between the two periods. The targeting strategies of Firm A and Firm B are characterized by their choices of x_A and x_B, which can be constrained by the number of consumers on whom firms have acquired information. In period 1, Firm A collects information on $[0, \tilde{x}_1]$ and Firm B collects information on $[\tilde{x}_1, 1]$. Therefore, the targeting strategy of each firm must verify: $x_A \leq \tilde{x}_1$ and $x_B \leq 1 - \tilde{x}_1$. Hence, competition in period 1 can have an impact on the targeting strategies of the firms. Note that the situation where each firm targets all its past customers is a special case of this approach, where $x_A = 1 - x_B = \tilde{x}_1$.

3.3.2. Equilibrium targeting

This section characterizes the optimal number of customers that each firm targets in period 2. Firm A price discriminates consumers on $[0, x_A]$, and charges a homogeneous price to consumers on $[x_A, 1]$. Similarly, Firm B price discriminates consumers on $[1 - x_B, 1]$, and charges a homogeneous price to consumers on $[0, 1 - x_B]$. The choices of x_A and x_B correspond to the targeting strategies of Firm A and Firm B, and their optimal values x_A^* and x_B^* are characterized in this section.

Each firm can target in period 2 customers that it has served in period 1, and the value of $\tilde{x}_1$ may constrain the targeting strategy of firms in period 2. Indeed, if $\tilde{x}_1 \in [x_A^*, 1 - x_B^*]$, both firms can target their optimal number of consumers in period 2. On the contrary, if $\tilde{x}_1 \in [0, x_A^*]$ or if $\tilde{x}_1 \in [1 - x_B^*, 1]$, respectively Firm A or Firm B cannot target their optimal number of consumers, and are constrained in their targeting strategy.

Proposition 2 characterizes the equilibria when $\tilde{x}_1 \in [x_A^*, 1 - x_B^*]$ and firms are not constrained on their targeting strategies, and when $\tilde{x}_1 \in [0, x_A^*]$ and Firm A is constrained (the case where Firm B is constrained is identical).

[21] See also more recently Chen et al. (2020).

Proposition 2.

- *(a) In period 2 when $\tilde{x}_1 \in [\frac{1}{3}, \frac{2}{3}]$ the subgame perfect equilibrium is unconstrained and firms target symmetric shares of consumers:*

$$x_A^* = x_B^* = \frac{1}{3}, \quad \tilde{x}_2 = \frac{1}{2}.$$

- *(b) In period 2 when $\tilde{x}_1 \in [0, \frac{1}{3}]$ the subgame perfect equilibrium is constrained and firms target asymmetric shares of consumers:*

$$x_A^* = \tilde{x}_1, \quad x_B^* = \frac{3}{7} - \frac{2\tilde{x}_1}{7}, \quad \tilde{x}_2 = \frac{6\tilde{x}_1 + 5}{14}.$$

Proof. See Appendix A.2.

In the unconstrained equilibrium characterized by Proposition 2 (a), both pricing algorithms design the same strategies in which firms target only part of their past customers. In period 2 Firm A and Firm B have information on consumers respectively in $[0, \tilde{x}_1]$ and $[\tilde{x}_1, 1]$ (with $\tilde{x}_1 \in [\frac{1}{3}, \frac{2}{3}]$), but they charge a homogeneous price on $[\frac{1}{3}, 1]$ and $[0, \frac{2}{3}]$ to soften competition.

Proposition 2 (b) characterizes the equilibrium when Firm A is constrained on its targeting strategy and price-discriminates fewer consumers than its unconstrained optimum. This relaxes the competitive pressure on Firm B, which targets more consumers and makes higher profits than in the symmetric equilibrium. Hence it is profitable for a firm to face a competitor constrained on targeting. This can be achieved by undercutting prices in period 1. Indeed, the value of $\tilde{x}_1$ in period 1 depends on the prices set by the firms, and the next section analyzes whether a firm has interest to undercut prices in period 1 in order to constrain the targeting strategy of its competitor in period 2.

An important element of the analysis is the locations of the indifferent consumers $\tilde{x}_1$ in period 1 and $\tilde{x}_2$ in period 2. Indeed, the literature usually finds that BBPD results in poaching practices: some consumers purchase from one firm in period 1, and then from its competitor in period 2. Poaching is considered beneficial for consumers as it results in a more competitive market in period 2 but yields overall inefficiency as some consumers do not buy the product closest to their taste. The next section shows that in the unique equilibrium of the game with strategic targeting, $\tilde{x}_1 = \tilde{x}_2$ and consumers do not switch from firms across periods, so that consumer poaching does not take place.

Note that firms face a prisoner's dilemma when using information to target customers: each firm is better off using information than charging a homogeneous price, but the increase in competitive intensity harms the industry so that the profits of the firms are lower in equilibrium than in the classical Hotelling model without information. Consider indeed the profits of the firms in period 2 (characterized in Appendix A.2):

$$\pi_{\theta 2} = \frac{t}{2} - \frac{7}{9}x_\theta^2 t + \frac{2}{9}x_{-\theta}^2 t - \frac{4}{9}x_\theta x_{-\theta} t + \frac{2}{3}x_\theta t - \frac{2}{3}x_{-\theta} t$$

Setting $x_\theta = x_{-\theta} = 0$ we obtain the Hotelling profits without information equal to $\frac{t}{2}$. From the situation where both firms are uninformed, Firm θ always has interest to use information as $\pi_{\theta 2}(x_\theta, x_{-\theta} = 0) = \frac{t}{2} - \frac{7}{9}x_\theta^2 t + \frac{2}{3}x_\theta t > \frac{t}{2}$. However, the profits of the firms in the unconstrained equilibrium (which we will see, dominates the constrained equilibrium) are equal to $\frac{7t}{18} < \frac{t}{2}$, and the industry loses from the ability of firms to target consumers.[22]

[22] We can simply find this value replacing x_θ and $x_{-\theta}$ by $\frac{1}{3}$ in the profit function.

We analyze in the next section how strategic targeting impacts the first period of competition.

3.4. Period 1: information acquisition

This section analyzes competition in the information acquisition period. In the symmetric equilibrium, firms maximize profits in period 1 and market equilibrium is identical to standard Hotelling competition without data collection. Proposition 3 states that the unique equilibrium is symmetric, and that price undercutting in period 1 to constrain a firm's competitor is not sustainable.

Proposition 3.

- *The unique pure strategy equilibrium of the game is symmetric.*
- *Firms do not engage in price-undercutting strategies.*
- *In both periods:*
  - *Consumers on* $[0, \frac{1}{2}]$ *purchase from Firm A.*
  - *Consumers on* $[\frac{1}{2}, 1]$ *purchase from Firm B.*
  - *Poaching does not take place.*

Proof. See Appendix A.3.

Firms do not have interest to engage in constraining strategies: to constrain their competitor in period 2, firms must undercut prices so that the indifferent consumer $\tilde{x}_1$ is very close to the competitor's location in period 1. For instance, if Firm B wants to constrain Firm A, it must be that $\tilde{x}_1 < \frac{1}{3}$. Reaching such a constraining market outcome induces an important loss in period 1 for a firm, and the increase in profits of period 2 is not sufficient to cover this loss.

The literature on BBPD classically finds that competition in the first period is driven by two main forces: firms want to reach high profits in this first period, but they also anticipate the second competition period in which they have information on their past customers. Hence, competition is fiercer than in the standard Hotelling model without information, as a firm has an additional incentive to serve a larger customer demand in period 1 to charge targeted prices to more consumers in the second period (Choe et al., 2018). This second dimension can be interpreted as a 'competition for information acquisition' in period 1. When firms use algorithmic pricing techniques, Proposition 3 shows that they do not charge targeted prices to consumers in the middle of the line, and thus they do not make additional benefits from identifying these consumers in period 1: firms do not compete to acquire consumer information.[23]

Moreover, the same consumer demands are served in both competition periods $\tilde{x}_1 = \tilde{x}_2$. This is a natural consequence of strategic targeting under which firms do not have interest to undercut prices and poach consumers, but soften competition by keeping a large share of consumers untargeted. This result contrasts with previous literature in which poaching occurs in period 2 and some consumers switch products (Fudenberg and Tirole, 2000). Hence, Proposition 3 also contributes to the literature by showing that the adoption of strategic targeting by firms allows them to avoid poaching and price undercutting in the second competition period.

Proposition 3 presents interesting connections with the results of Choe et al. (2018), who show in a similar setting without strategic targeting that the only equilibrium is asymmetric, and poaching occurs in period 2. Proposition 3 states that when firms use pricing algorithms, the equilibrium of the game is symmetric. Pricing algorithms give firms the ability to commit to their targeting strategy, a central precondition for partial consumer targeting to take place. In the case where firms cannot commit, they charge personalized prices to all their past customers and the equilibrium is identical to Choe et al. (2018). Hence, firms' commitments to their targeting strategies have important managerial implications, which are discussed in Section 5.

4. Forward-looking consumers

Consumers may anticipate in period 1 that firms collect their information to charge targeted prices in period 2 (Li and Jain, 2016). This ability of consumers to anticipate BBPD and purchase products accordingly is a classical consideration of the literature that usually finds a reduction of competition in the information acquisition period as demand becomes less price-sensitive (Fudenberg and Tirole, 2000).

This section considers consumers located in $[0, \frac{1}{3}]$ who anticipate that firms use pricing algorithms and that they will be charged a targeted price in period 2. It analyzes whether these consumers have interest to purchase from Firm B in period 1 in order to remain hidden from Firm A and pay a homogeneous price in period 2. When choosing which product to purchase in the first period, consumers maximize the sum of utilities over both periods by discounting period 2 with a factor δ_c.

Proposition 4.

- *The unique equilibrium in both competition periods is identical to the case with myopic consumers.*
- *Strategic consumers purchase from the same firm in both competition periods and do not engage in hiding strategies.*

Proof. See Appendix A.4.

Proposition 4 states that consumers do not have interest to hide from firms, and the equilibrium is identical to the baseline framework with myopic consumers. This result contributes to previous literature that has shown that consumers have interest to change their consumption behavior when they are relatively indifferent between the products of both firms (Fudenberg and Tirole, 2000).

When firms engage in behavior-based algorithmic pricing, only consumers with high valuations for a firm's product are targeted in the second period and may have interest to purchase their least preferred product in the first period. Of course, in practice consumers switch between different brands, which can be explained by many factors. For instance, consumers may discover their true taste for a product after its consumption, or firms can engage in product personalization changing the willingness to pay of consumers for their products. Nevertheless, this analysis suggests that switching is less likely to occur when firms use customer information strategically. Purchasing Firm B's product in period 1 would induce an important opportunity cost for a consumer close to Firm A, which is not recovered in period 2, and consumers purchase their preferred product in both periods. Hence, consumers have no interest to hide when firms use strategic targeting.[24]

5. Conclusion

This article has analyzed the impacts of pricing algorithms on product market competition. Highlighting the potential role of these algorithms as commitment devices for firms, we have seen that new anti-competitive effects may be expected from this type of pricing technique. Notably, these effects do not arise from long-term relations, the main mechanism analyzed by a large body of the literature

[23] Interestingly, Fudenberg and Tirole (2000) also find that competition in the first period is identical to the standard Hotelling framework when consumers are myopic. In our model, we will see in Section 4 that this result holds also with forward-looking consumers.

[24] This result holds when one of the firms engages in a constraining strategy and undercuts prices in the first competition period (the proof is available upon request).

(Liu and Serfes, 2007; Calvano et al., 2020), but rely on the possibility for firms to design sophisticated pricing strategies. These results have direct implications for policymakers assessing the potential harms of pricing algorithms for consumers.

The results derived in this analysis rely on the possibility for the firms to commit to a targeting strategy. Such a strategic commitment could be attained for instance through the public adoption of a pricing software by firms. The number of pricing software has indeed increased sharply in the past years, companies such as Vendavo, Glew, Pricemoov or Price2spy now sell their software to major companies in any type of industry, and the adoption of one of these services by a company is usually public.[25] For the commitment to be deviation-proof, firms must not be able to use another pricing algorithm allowing to identify all past customers. This could be guaranteed for large companies as any information disclosed to shareholders is legally binding: the firm cannot lie to its shareholders, in particular when it comes to its technological and market strategies. A firm claiming to use a pricing software while it does not use it would be exposed to legal actions.

This simple two-period competition framework could be extended to account for positive data collection costs. Collecting, treating, and storing data is indeed costly, and may reduce the profitability of consumer targeting for firms. In particular, asymmetric data collection costs can provide a firm with a significant competitive advantage and could restore asymmetric competition.

CRediT authorship contribution statement

Antoine Dubus: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Data availability

No data was used for the research described in the article.

Appendix A

A.1. Proof of Proposition 1

This section characterizes the optimal targeting strategy of Firm A. For any given partition used by Firm B, I show that the optimal partition for Firm A is composed of one type (a) segment closest to its location where all consumers are charged personalized prices, and one type (b) segment on the rest of the line where consumers are charged a uniform price. The proof of the optimal partition for Firm B follows the same reasoning.

Firm A can choose any partition $\mathcal{X}_A \in \Psi_A(\tilde{x}_1)$ for a given $\tilde{x}_1$. There are three types of segments to consider:

- Segments α, where Firm A is in constrained monopoly;
- Segments β, where Firms A and B compete.
- Segments γ, where Firm A makes zero profit.

All segments in $\mathcal{X}_A^a$ are necessarily of type α, while segments in $\mathcal{X}_A^b$ may be of type α, β, and γ.

To find the partition that maximizes the profits of Firm A, the proof proceeds in three steps. Step 1 analyzes type α segments, and shows that it is optimal for Firm A to first-degree price discriminate all consumers in these segments. Step 2 shows that all segments of type α are located closest to Firm A. Step 3 analyzes segments of type β and shows that it is always more profitable to target a union of such segments. Therefore, there is only one segment of type β, located furthest away from Firm A, and of size $1 - x_A$. Finally, segments of type γ can be discarded because information on consumers in these segments does not increase profits.

[25] See for instance Glew customers, last accessed, March 14, 2023.

Step 1: I analyze segments of type α where Firm A is in constrained monopoly, and show that targeting all consumers is optimal.

Consider any segment $I = [i, i + l]$ of type α with l, i verifying $i + l \leq 1$, such that Firm A is in monopoly on this segment, constrained by Firm B charging price p_B. I compare profits with first and third-degree price discrimination and I show that the former is more profitable for Firm A. I write π_A^{third} and π_A^{first} the profits of Firm A on I with third-degree and first-degree price discrimination.

To prove this claim, I establish that π_A^{first} is greater than π_A^{third}. First, profits with first-degree price discrimination are: $\pi_A^{first} = \int_i^{i+l} p_A(x)dx$. The demand is l as Firm A gets all consumers by assumption.

$$V - tx - p_A(x) = V - t(1 - x) - p_B \implies p_A(x) = t - 2tx + p_B.$$

Note that price p_B is only affected by strategic interactions on the segments where firms compete, and therefore does not depend on the pricing strategy of Firm A on type α segments. I write the profit function for any p_2, replacing p_A:

$$\pi_A^{third} = l(t + p_B - 2(l + i)t).$$

Secondly, using a similar argument, I show that the profit with first-degree price discrimination is:

$$\pi_A^{first} = \int_i^{i+l} \left(t - 2tx + p_B\right) dx.$$

Comparing π_A^{third} and π_A^{first} shows that the profit of Firm A using the first-degree price discrimination is higher than under third-degree price discrimination, which establishes the claim. Therefore, in equilibrium, there is no type α segment in the set $\mathcal{X}_\theta^b$.

Step 2: I show that all segments of type α are closest to Firm A (located at 0 on the unit line by convention).

Going from left to right on the Hotelling line, look for the first time where a type β interval, $J = [i; i + l]$ of length l, is followed by an interval $I = [i + l, i + l + \epsilon]$ of type α.

A simple comparison allows to show that a reordering of the overall interval $J \cup I = [i, i + l + \epsilon]$ in two intervals $I' = [i; i + \epsilon]$ and $J' = [i + \epsilon, i + l + \epsilon]$ increases the profit of Firm A. Indeed, after the re-ordering, full surplus is extracted from consumers in I', who have the highest valuation on this interval. All consumers located on J' are charged a homogeneous price, which softens the competitive pressure on Firm B compared with $J \cup I$ and increases the competitive price charged by Firm B. By iteration, I conclude that type α segments are always at the left of type β segments.

Step 3: I now analyze segments of type β where firms compete. For Firm A, starting from any partition with at least two segments of type β, I show that a coarser partition always increases the profits of Firm A.

The two previous steps have shown that an optimal partition must be composed for each firm of one type α segment closest to its location and potentially several type β segments on the rest of the line, as illustrated in Fig. 3.

The first two lines represent respectively the partitions used by Firm A and by Firm B. The thick black lines correspond to the consumers who are charged a personalized price by the closest firm. On each remaining segment of the first line, Firm A charges a homogeneous price: p_{A12} on the first segment starting from the left, p_{A22} on the second segment, and so on. Similarly on the second line, Firm B charges homogeneous price p_{B12} on the first segment after the thick line, starting from the right, price p_{B22} on the second segment and so on.

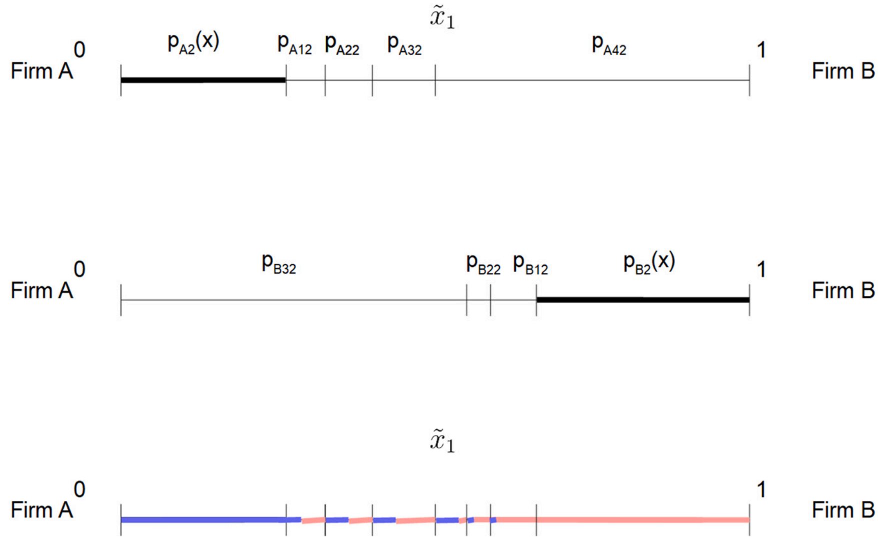

Fig. 3. Structures of the optimal partitions for each firm after applying steps 1 and 2.

The third line represents the resulting consumer demands, with in blue the demand of Firm A and in red the demand of Firm B. In each segment where a homogeneous price is charged by both firms, both firms reach a positive consumer demand, or else, one of the firms would charge personalized prices following step 1.

We want to show that the optimal partition has only one type β segment where firms charge a homogeneous price (contrary to four segments for Firm A and three segments for Firm B in the above example).

To do so, we show that if Firm A has a partition $\mathcal{X}_1$ with at least two segments where it competes with Firm B, a coarser partition $\mathcal{X}_1'$ where the two adjacent segments located closest to Firm A are merged yields higher profits.

Using a coarser partition has two opposite effects on the profits of Firm A. On the one hand, Firm A relaxes the competitive pressure on Firm B who will increase its price. This benefits Firm A on the coarser segments, and also on other segments where it can increase its price in turn. On the other hand, Firm A extracts less surplus from consumers located in the closest of the two merged segments. Indeed, when the segments were separated, Firm A could charge a higher price to these consumers than the price set on the merged segments with the coarser partition, and extract more of their surplus. The aim of the proof is to show that this second effect is always dominated by the first, positive effect, and that the profits of Firm A increase with coarser partitions.

Note that the homogeneous price charged by Firm B increases when Firm A uses a coarser partition. Hence, the demand of Firm B decreases in all segments where it charges this homogeneous price, and there can be some of these segments where Firm B does not reach a positive demand if Firm A uses a coarser partition. This requires us to account for these changes when computing the profits of Firm A with the coarser partition. I compute the profits of Firm A on all the segments where firms compete. There are three types of segments to consider:

- (1) segments of type α that with partition $\mathcal{X}_1$ that remain of type α with partition $\mathcal{X}_1'$.
- (2) segments of type β with partition $\mathcal{X}_1$ that become of type α with partition $\mathcal{X}_1'$.
- (3) segments of type β with partition $\mathcal{X}_1$ that remain of type β with partition $\mathcal{X}_1'$.

Note that there exists $\tilde{x}_B$ such that Firm B charges a homogeneous price on segment $[0, \tilde{x}_B]$ with $\tilde{x}_B > \tilde{x}_1$. Throughout the resolution we denote by $\hat{p}_B$ this price under partition $\mathcal{X}_1$ and $\hat{p}_B'$ with partition $\mathcal{X}_1'$. Similarly, there exists $\tilde{x}_A$ such that Firm A charges a homogeneous price on segment $[\tilde{x}_A, 1]$ with $\tilde{x}_A < \tilde{x}_1$. Throughout the resolution we denote by $\hat{p}_A$ this price under partition $\mathcal{X}_1$ and $\hat{p}_A'$ with partition $\mathcal{X}_1'$. Moreover, for simplicity we denote by $\hat{p}_{Ai}$ and $\hat{p}_{Bi}$ the homogeneous prices charged by Firm A and Firm B on their type β segments.

Profits always increase on segments that are of type α with partitions $\mathcal{X}_1$ and $\mathcal{X}_1'$. Indeed, I will show that $\hat{p}_B'$ with partition $\mathcal{X}_1'$ is higher than $\hat{p}_B$ with partition $\mathcal{X}_1$, and thus the profits of Firm A on type α segments increase.

It will also be useful to introduce the following notations. On interval $[0, \tilde{x}_A]$, there are n segments where firms compete. Among them, there are m segments which are type β in partition $\mathcal{X}_1$, but are no longer necessarily of type β in partition $\mathcal{X}_1$ (and are therefore of type α). There are $n+1-m$ segments of type β with partition $\mathcal{X}_1$ that remain of type β with partition $\mathcal{X}_1'$. I compute prices and profits on these $n+1$ segments.

On interval $[\tilde{x}_A, \tilde{x}_B]$, withe partition $\mathcal{X}_1$ ($\mathcal{X}_1'$) Firm A charges price $\hat{p}_A$ ($\hat{p}_A'$) and Firm B charges price $\hat{p}_B$ ($\hat{p}_B'$).

To compare the profits of the informed firm under both partitions, I first characterize type β segments. A segment of type β is non null if the following restrictions imposed by the structure of the model are met: respectively positive demand and the existence of competition on segments of type β. In order to characterize type α and type β segments, it is useful to consider the following inequality:

$$\forall \;\; i, l \in [0,1] \;\; s.t. \;\; 0 \le l \le 1-i$$

$$\text{Firm A serves some consumers on } [i, l] : i \le \frac{\hat{p}_B + t}{2t} \tag{5}$$

$$\text{Firm B serves some consumers on } [i, l] : \frac{\hat{p}_B + t}{2t} \le i + l.$$

In particular, I use the relation that Eq. (5) draws between price $\hat{p}_B$ and segments endpoints i and $i+l$ to compare the profits of Firm A with partitions $\mathcal{X}_1$ and $\mathcal{X}_1'$. Without loss of generality, I rewrite the notation of type α and β segments. The segment of type α is of size ϵ and is located at $u_i - \epsilon$, and segments of type β are located at s_i and are of size l_i.[26] On interval $[0, \tilde{x}_B]$, here are $n \in \mathbb{N}$ segments of type β, where prices are noted $\hat{p}_{Ai}^{\beta}$. On interval $[\tilde{x}_B, 1]$, there are n' segments where firms compete with Firm A charging price $\hat{p}_A$ and Firm B charging prices $\hat{p}_B$ and $\hat{p}_{Bi}^{\beta}$.

Our next point will be to show that profits on interval $[0, \tilde{x}_B]$ where Firm B charges a homogeneous price increase with partition $\mathcal{X}_1'$. Profits on interval $[\tilde{x}_B, 1]$ clearly increase, as we will show that $\hat{p}_B$ increases, relaxing the competitive pressure on Firm A in this interval.

[26] With u_i and s_i lower than 1.

I find the demand for Firm A on segments in $[0, \tilde{x}_B]$ using the location of the indifferent consumer:

$$d_{Ai} = x - s_i = \frac{\hat{p}_B - \hat{p}^{\beta}_{Ai} + t}{2t} - s_i.$$

I can rewrite the profits of Firm A as the sum of four terms. The first term represents the profits on segments of type α. The second term is the profits on segments of type β on interval $[0, \tilde{x}_A]$. The third term $\hat{p}_A[\frac{\hat{p}_A - \hat{p}_B + t}{2t} - \tilde{x}_A]$ is the profit on $[\tilde{x}_A, \tilde{x}_B]$ where both firms charge their homogeneous prices $\hat{p}_A$ and $\hat{p}_B$. The fourth term represents the profits on segments of type β on interval $[\tilde{x}_B, 1]$ where Firm A charges its homogeneous price $\hat{p}_A$ and Firm B charges different prices on different segments of its partition.

$$\pi_A(\mathcal{X}_1) = \int_0^{s_1} \hat{p}^{\alpha}_A(x)dx + \sum_{i=1}^{n} \hat{p}^{\beta}_{Ai}[\frac{\hat{p}_B - \hat{p}^{\beta}_{Ai} + t}{2t} - s_i]$$
$$+ \hat{p}_A[\frac{\hat{p}_A - \hat{p}_B + t}{2t} - \tilde{x}_A] + \sum_{i=1}^{n'} \hat{p}_A[\frac{\hat{p}^{\beta}_{Bi} - \hat{p}_A + t}{2t} - s_i].$$

The price $\hat{p}_B$ is chosen by Firm B to maximize local profits generated on segments of type β only, where the demand for Firm B is:

$$d_{Bi} = s_i + l_i - x = \frac{\hat{p}^{\beta}_{Ai} - \hat{p}_B - t}{2t} + s_i + l_i.$$

Firm B sets price $\hat{p}_B$ to maximize profits on interval $[0, \tilde{x}_B]$, which can be written as:

$$\pi_{Bl}(\mathcal{X}_1) = \sum_{i=1}^{n} \hat{p}_B[\frac{\hat{p}^{\beta}_{Ai} - \hat{p}_B - t}{2t} + s_i + l_i]. \quad (6)$$

Firm A maximizes profits $\pi_A(\mathcal{X}_1)$ with respect to $\hat{p}^{\alpha}_A(x)$, $\hat{p}^{\beta}_{Ai}$ and $\hat{p}_A$, and Firm B maximizes $\pi_{Bl}(\mathcal{X}_1)$ with respect to $\hat{p}_B$, both profits are strictly concave.

Equilibrium prices are:

$$\hat{p}_B = -\frac{t}{3} + \frac{4t}{3(n+1)} \sum_{i=1}^{n+1} [\frac{s_i}{2} + l_i],$$
$$\hat{p}^{\beta}_{Ai} = \frac{\hat{p}_B + t}{2} - s_i t$$
$$= \frac{t}{3} + \frac{2t}{3(n+1)} \sum_{i=1}^{n+1} [\frac{s_i}{2} + l_i] - s_i t.$$

Let $\hat{p}^{\beta}_{1s}$ and $\hat{p}^{\beta}_{1s+l}$ be the prices on the first two segments when the partition is $\mathcal{X}_1$.

$$\hat{p}^{\beta}_{1s} = \frac{\hat{p}_B + t}{2} - \frac{st}{k},$$
$$\hat{p}^{\beta}_{1s+l} = \frac{\hat{p}_B + t}{2} - \frac{s+l}{k} t,$$

$\hat{p}'_B$ is the price set by Firm B with partition $\mathcal{X}'_1$, and $\hat{p}^{\beta'}_{1s}$ is the price set by Firm A on the last segment of partition $\mathcal{X}'_1$.

When the partition used by Firm A becomes coarser, the prices charged by Firm B on the left segment increase. Inequalities in Eq. (5) might not hold as price $\hat{p}_B$ varies depending on the partition acquired by Firm A. This implies that some segments which are of type β with partition $\mathcal{X}_1$ are then of type α with partition $\mathcal{X}'_1$. I note $\tilde{s}_i$ the m segments where it is the case. I then have:

$$\hat{p}'_B = \frac{4t}{3(n-m)}[-\frac{n-m}{4} + \sum_{i=1}^{n} [\frac{s_i}{2} + l_i] - \sum_{i=1}^{m} \frac{\tilde{s}_i}{2}]$$
$$= \frac{4t}{3(n-m)}[-\frac{n+1}{4} + \sum_{i=1}^{n+1} [\frac{s_i}{2} + l_i] + \frac{m+1}{4} - \sum_{i=1}^{m} \frac{\tilde{s}_i}{2} - \frac{s+l}{2}]$$
$$= \hat{p}_B + \frac{4t}{3(n-m)}[\frac{3(m+1)\hat{p}_B}{4t} + \frac{m+1}{4} - \sum_{i=1}^{m} \frac{\tilde{s}_i}{2} - \frac{s+l}{2}] \quad (7)$$
$$\geq \hat{p}_B + \frac{4t}{3(n-m)}[\frac{3}{4t}\hat{p}_B + \frac{m\hat{p}_B}{2t} + \frac{1}{4} - \frac{s+l}{2}],$$

$$\hat{p}^{\beta'}_{1s} = \frac{\hat{p}_B + t}{2} - \frac{st}{k},$$

$$\pi_A(\mathcal{X}_1) = \sum_{i=1, s_i \neq \tilde{s}_i}^{n} p_{Ai}[\frac{\hat{p}_B + t}{4t} - \frac{s_i}{2}]$$
$$+ \sum_{i=1}^{m} \hat{p}^{\beta}_{Ai}[\frac{\hat{p}_B + t}{4t} - \frac{\tilde{s}_i}{2}] + \hat{p}^{\beta}_{1s+l}[\frac{\hat{p}_B + t}{4t} - \frac{s+l}{2}]$$
$$+ \sum_{i=1}^{n'} \hat{p}_A[\frac{\hat{p}^{\beta}_{Bi} - \hat{p}_A + t}{2t} - s_i]$$

$$\pi_A(\mathcal{X}'_1) = \sum_{i=1, s_i \neq \tilde{s}_i}^{n} \hat{p}^{\beta'}_{Ai}[\frac{\hat{p}'_B + t}{4t} - \frac{s_i}{2}] + \sum_{i=1}^{m} \frac{\tilde{l}_i}{k}[\hat{p}'_B + t - 2t\frac{\tilde{s}_i + \tilde{l}_i}{k}]$$
$$+ \sum_{i=1}^{m'} \hat{p}'_A[\frac{\hat{p}^{\beta'}_{Bi} - \hat{p}'_A + t}{2t} - s_i].$$

I compare the profits of Firm A in both cases in order to show that $\mathcal{X}'_1$ induces higher profits. Clearly, because $\hat{p}'_B > \hat{p}_B$, we have that:

$$\hat{p}_A[\hat{p}_B - \frac{\hat{p}_A + t}{2t} - \tilde{x}_A] + \sum_{i=1}^{n'} \hat{p}_A[\hat{p}^{\beta}_{Bi} - \frac{\hat{p}_A + t}{2t} - s_i]$$
$$> \hat{p}'_A[\hat{p}'_B - \frac{\hat{p}'_A + t}{2t} - \tilde{x}_A] + \sum_{i=1}^{m'} \hat{p}'_A[\frac{\hat{p}^{\beta'}_{Bi} - \hat{p}'_A + t}{2t} - s_i].$$

Hence, we focus on the rest of the expression in the remaining of the proof:

$$\Delta\pi_A = \pi_A(\mathcal{X}'_1) - \pi_A(\mathcal{X}_1)$$
$$\geq \sum_{i=1, s_i \neq \tilde{s}_i}^{n} \hat{p}^{\beta'}_{Ai}[\frac{\hat{p}'_B + t}{4t} - \frac{s_i}{2}] - \sum_{i=1, s_i \neq \tilde{s}_i}^{n} \hat{p}^{\beta}_{Ai}[\frac{\hat{p}_B + t}{4t} - \frac{s_i}{2}]$$
$$+ \sum_{i=1}^{m} \frac{\tilde{l}_i}{k}[\hat{p}'_B + t - 2t\frac{\tilde{s}_i + \tilde{l}_i}{k}] - \sum_{i=1}^{m} \hat{p}^{\beta}_{Ai}[\frac{\hat{p}_B + t}{4t} - \frac{\tilde{s}_i}{2}]$$
$$- \hat{p}^{\beta}_{1s+l}[\frac{\hat{p}_B + t}{4t} - \frac{s+l}{2}]$$
$$= \frac{t}{2} \sum_{i=1, s_i \neq \tilde{s}_i}^{n} [\frac{\hat{p}'_B + t}{2t} - s_i]^2 - \frac{t}{2} \sum_{i=1, s_i \neq \tilde{s}_i}^{n} [\frac{\hat{p}_B + t}{2t} - s_i]^2$$
$$+ \frac{t}{2} \sum_{i=1}^{m} \frac{\tilde{l}_i}{k}[2\frac{\hat{p}'_B + t}{t} - 4\frac{\tilde{s}_i + \tilde{l}_i}{k}]$$
$$- \frac{t}{2} \sum_{i=1}^{m} [\frac{\hat{p}_B + t}{2t} - \frac{\tilde{s}_i}{2}]^2 - \frac{t}{2}[\frac{\hat{p}_B + t}{2t} - \frac{s+l}{k}]^2.$$

I consider the terms separately. First,

$$\frac{t}{2} \sum_{i=1, s_i \neq \tilde{s}_i}^{n} [\frac{\hat{p}'_B + t}{2t} - s_i]^2 - \frac{t}{2} \sum_{i=1, s_i \neq \tilde{s}_i}^{n} [\frac{\hat{p}_B + t}{2t} - s_i]^2$$
$$= \frac{t}{2} \sum_{i=1, s_i \neq \tilde{s}_i}^{n} [[\frac{2}{3(n-m)}[\frac{3}{4t}\hat{p}_B + \frac{m\hat{p}_B}{2t} + \frac{1}{4} - \frac{s+l}{2}]]^2$$
$$+ [\frac{\hat{p}_B + t}{2t} - s_i][\frac{4}{3(n-m)}[\frac{3}{4t}\hat{p}_B + \frac{m\hat{p}_B}{2t} + \frac{1}{4} - \frac{s+l}{2}]]]$$
$$\geq \frac{t}{2}[\frac{\hat{p}_B + t}{2t} - \frac{s+l}{k}]\frac{4}{3}[\frac{3}{4t}\hat{p}_B + \frac{m\hat{p}_B}{2t} + \frac{1}{4} - \frac{s+l}{2}].$$

Secondly, on segments of type β with partition $\mathcal{X}_1$ that are of type α with partition $\mathcal{X}'_1$:

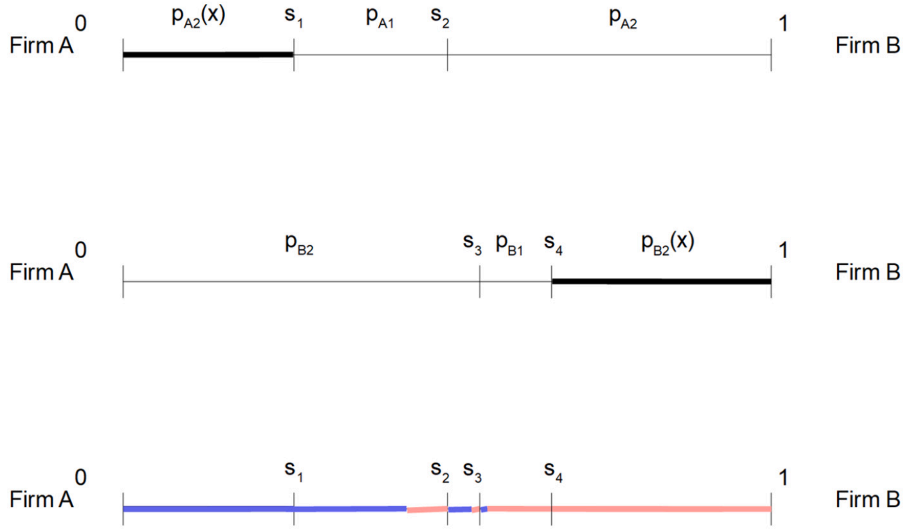

Fig. 4. Structures of the optimal partitions for each firm after applying steps 1, 2, and the previous part of step 3.

$$\frac{t}{2}\sum_{i=1}^{m}\frac{\tilde{l}_i}{k}[2\frac{\hat{p}'_B+t}{t}-4\frac{\tilde{s}_i+\tilde{l}_i}{k}]-\frac{t}{2}\sum_{i=1}^{m}[\frac{\hat{p}_B+t}{2t}-\frac{\tilde{s}_i}{2}]^2.$$

On these m segments, inequalities in Eq. (5) hold for price $\hat{p}'_B$ but not for $\hat{p}_B$. Thus I can rank prices according to $\tilde{s}_i$ and $\tilde{l}_i$:

$$\frac{\tilde{s}_i+\tilde{l}_i}{k}\geq\frac{\hat{p}_B+t}{2t}-\frac{\tilde{l}_i}{k}\quad\text{and}\quad\frac{\hat{p}'_B+t}{2t}-\frac{\tilde{l}_i}{k}\geq\frac{\tilde{s}_i+\tilde{l}_i}{k}.$$

thus:

$$2\frac{\tilde{l}_i}{k}\geq\frac{\hat{p}_B+t}{2t}-\tilde{s}_i\quad\text{and}\quad\frac{\hat{p}'_B+t}{2t}-2\frac{\tilde{l}_i}{k}\geq\tilde{s}_i.$$

By replacing $\tilde{s}_i$ by its upper bound value and then $\tilde{l}_i$ by its lower bound value I obtain:

$$\frac{t}{2}\sum_{i=1}^{m}\frac{\tilde{l}_i}{k}[2\frac{\hat{p}'_B+t}{t}-4\frac{\tilde{s}_i+\tilde{l}_i}{k}]-\frac{t}{2}\sum_{i=1}^{m}[\frac{\hat{p}_B+t}{2t}-\frac{\tilde{s}_i}{2}]^2\geq 0.$$

Getting back to the profits difference, I obtain:

$$\begin{aligned}\Delta\pi_A &\geq \frac{t}{2}[\frac{\hat{p}_B+t}{2t}-\frac{s+l}{k}]\frac{4}{3}[\frac{3}{4t}\hat{p}_B+\frac{m\hat{p}_B}{2t}+\frac{1}{4}-\frac{s+l}{2}]\\ &\quad-\frac{t}{2}[\frac{\hat{p}_B+t}{2t}-\frac{s+l}{k}]^2 \\ &\geq \frac{t}{2}[\frac{\hat{p}_B+t}{2t}-\frac{s+l}{k}][\frac{\hat{p}_B}{2t}+\frac{s+l}{3k}-\frac{1}{6}].\end{aligned}\tag{8}$$

The first bracket of Equation (8) is positive given Eq. (5). The second bracket is positive if $\frac{\hat{p}_B}{2t}+\frac{s+l}{3k}\geq\frac{1}{6}$. A sufficient condition for this result to hold is $\hat{p}_B\geq\frac{t}{3}$. I prove that this inequality is always satisfied by showing that the partition that contains all segments minimizes the price and profit of Firm B, and that in this case, $\hat{p}_B\geq\frac{t}{2}$.[27] And as this price is greater than $\frac{1}{6}$, the second bracket of Equation (8) is positive. This proves that $\Delta\pi_A\geq 0$.

At this point of the step, we have shown that it is always optimal for each firm to use a partition with the following shape: each firm uses a partition with at most two segments of type β located furthest from its location. If both firms have only one such segment in the middle of the line, the proof is completed. If one firm has two segments of type β and the other firm has one segment of type β, the step above directly applies, and the transformation consisting in merging both type β segments is profit increasing for the firm.

If both firms have two type β segments, we must show that such partition - denoted X_A - always yields lower profits than the same partition but with the two type β segments merged into one type β segment - denoted X'_A (we denote by X_B the partition of Firm B). This is the last part of the proof, which is established now. Such partition is depicted on Fig. 4.

The profits of Firm A can be written:

$$\pi_A(X_A)=\int_0^{s_1}\hat{p}^{\alpha}_A(x)dx+\hat{p}_{A1}[\frac{\hat{p}_{B2}-\hat{p}_{A1}+t}{2t}-s_1]$$
$$+\hat{p}_{A2}[\frac{\hat{p}_{B2}-\hat{p}_{A2}+t}{2t}-s_2]+\hat{p}_{A2}[\frac{\hat{p}_{B1}-\hat{p}_{A2}+t}{2t}-s_3].$$

$$\pi_B(X_B)=\int_{s_4}^{1}\hat{p}^{\alpha}_B(x)dx+\hat{p}_{B1}[s_4-\frac{\hat{p}_{B1}-\hat{p}_{A2}+t}{2t}]$$
$$+\hat{p}_{B1}[s_3-\frac{\hat{p}_{B1}-\hat{p}_{A2}+t}{2t}]+\hat{p}_{B2}[s_2-\frac{\hat{p}_{B1}-\hat{p}_{A2}+t}{2t}].$$

We can show that the profits of Firm A are lower than when merging the two type β segments and choosing an optimal s_1^* such that all consumers are charged a targeted price on $[0,s_1^*]$ and one homogeneous price on $[s_1^*,1]$. We need to consider two cases. Either Firm A makes positive profits on $[s_3,s_4]$ and makes profits as follows:

$$\pi_A(X'_A)=\int_0^{s_1^*}\hat{p}^{\alpha}_A(x)dx+\hat{p}'_{A1}[\frac{\hat{p}_{B2}-\hat{p}'_{A1}+t}{2t}-s_1^*]$$
$$+\hat{p}'_{A1}[\frac{\hat{p}_{B1}-\hat{p}'_{A1}+t}{2t}-s_3].$$

$$\pi_B(X'_B)=\int_{s_4}^{1}\hat{p}^{\alpha}_B(x)dx+\hat{p}_{B1}[s_4-\frac{\hat{p}_{B1}-\hat{p}'_{A1}+t}{2t}]$$
$$+\hat{p}_{B2}[s_3-\frac{\hat{p}_{B2}-\hat{p}'_{A1}+t}{2t}].$$

Or Firm A does not make positive profits on $[s_3,s_4]$ and makes profits as follows:

$$\pi_A(X'_A)=\int_0^{s_1^*}\hat{p}^{\alpha}_A(x)dx+\hat{p}'_{A1}[\frac{\hat{p}_{B2}-\hat{p}'_{A1}+t}{2t}-s_1^*].$$

[27] As shown in Liu and Serfes (2004).

$$\pi_A(X_B) = \int_{s_4}^{1} \hat{p}_B^{\alpha}(x)dx + \hat{p}_{B1}[s_4 - \frac{\hat{p}_{B1} - \hat{p}'_{A1} + t}{2t}]$$
$$+ \hat{p}_{B1}[s_3 - \frac{\hat{p}_{B1} - \hat{p}'_{A1} + t}{2t}] + \hat{p}_{B2}[s_2 - \frac{\hat{p}_{B2} - \hat{p}'_{A1} + t}{2t}].$$

Having stated this problem, I provide the details of the resolution in the online Appendix. Overall, this last transformation increases the profits of Firm A.

Conclusion

This result allows us to establish that it is always more profitable for Firm A to use a partition with one segment of type β than to use a partition with several segments of type β.

These three steps prove that the optimal partition for each firm includes two intervals: Firm A first-degree price discriminates consumers on interval $[0, x_A]$, and charges a homogeneous price on the second interval located at $[x_A, 1]$. By symmetry, it is optimal for Firm B to target all consumers on interval $[1 - x_B, 1]$ and to charge a homogeneous price to consumers on $[0, 1 - x_B]$. □

A.2. Proof of Proposition 2

I characterize the optimal targeting strategies of the firms in period 2. I first compute prices and demands in period 2 when firms target consumers strategically. Firm A chooses the value of x_A such that it price discriminates consumers on $[0, x_A]$, and charges consumers on $[x_A, 1]$ a homogeneous price. Similarly, Firm B price discriminates consumers on $[1 - x_B, 1]$, and charges a homogeneous price to consumers on $[0, 1 - x_B]$. The choices of x_A and x_B correspond to the targeting strategies of Firm A and Firm B. I will provide prices and profits in period 2, and I will characterize x_A and x_B.

Prices and demand.

Firm A sets a price $p_{A2}(x)$ for consumers located at $[0, x_1]$. Similarly, Firm B sets a price $p_{B2}(x)$ for consumers located at $[1 - x_B, 1]$. Firm θ then sets a unique price $p_{\theta 2}$ on the rest of the unit line. The prices charged to consumers targeted by Firm A satisfy:

$$V - tx - p_{A2}(x) = V - t(1 - x) - p_{B2}$$
$$\implies x = \frac{p_{B2} - p_{A2}(x) + t}{2t}$$
$$\implies p_{A2}(x) = p_{B2} + t - 2tx.$$

Firm B charges homogeneous price p_{B2} on interval $[0, 1 - x_B]$, and charges targeted prices on $[1 - x_B, 1]$:

$$p_{B2}(x) = p_{A2} - t + 2tx.$$

Let denote d_{A2} the demand for Firm A (resp. d_{B2} the demand for Firm B) where firms compete. d_{A2} is determined by the indifferent consumer $\tilde{x}_2$:

$V - t\tilde{x}_2 - p_{A2} = V - t(1 - \tilde{x}_2) - p_{B2} \implies \tilde{x}_2 = \frac{p_{B2} - p_{A2} + t}{2t}$ and $d_{A2} = \tilde{x}_2 - x_A = \frac{p_{B2} - p_{A2} + t}{2t} - x_A$ (resp. $d_{B2} = 1 - x_B - \frac{p_{B2} - p_{A2} + t}{2t}$).

Profits of the firms.

The profits of the firms are:

$$\pi_{A2} = \int_{0}^{x_A} p_{A2}(x)dx + d_{A2}p_{A2}$$
$$= \int_{0}^{x_A} (p_{B2} + t - 2tx)dx + (\frac{p_{B2} - p_{A2} + t}{2t} - x_A)p_{A2},$$

$$\pi_{B2} = \int_{1-x_B}^{1} p_{B2}(x)dx + d_{B2}p_{B2}$$
$$= \int_{1-x_B}^{1} (p_{A2} - t + 2tx)dx + (\frac{p_{A2} - p_{B2} + t}{2t} - x_B)p_{B2}.$$

Prices and demands in equilibrium.

I now compute the optimal prices and demands, using first-order conditions on π_θ with respect to p_θ. Prices in equilibrium are:

$$p_{A2} = t[1 - \frac{2}{3}x_B - \frac{4}{3}x_A],$$
$$p_{B2} = t[1 - \frac{2}{3}x_A - \frac{4}{3}x_B].$$

I rule out negative prices from the analysis: $p_{\theta 2}$ is taken equal to zero in case its above expression is negative.

Replacing these values in the above demands and prices gives:

$$p_{A2}(x) = 2t - \frac{4t}{3}x_B - \frac{2t}{3}x_A - 2tx,$$
$$p_{B2}(x) = 2tx - \frac{4t}{3}x_A - \frac{2t}{3}x_B$$

Demands in equilibrium are as follows:

$$d_{A2} = \frac{1}{2} - \frac{2}{3}x_A - \frac{1}{3}x_B,$$
$$d_{B2} = \frac{1}{2} - \frac{2}{3}x_B - \frac{1}{3}x_A.$$

Profits in equilibrium.

I compute profits by replacing prices and demands by their equilibrium values:

$$\pi_{\theta 2} = \frac{t}{2} - \frac{7}{9}x_\theta^2 t + \frac{2}{9}x_{-\theta}^2 t - \frac{4}{9}x_\theta x_{-\theta} t + \frac{2}{3}x_\theta t - \frac{2}{3}x_{-\theta} t.$$

Profits are strictly concave functions with respect to x_A and x_B, and they have a unique maximum.

Optimal targeting strategies: unconstrained.

I derive the optimal targeting strategies x_A^* and x_B^* of Firm A and Firm B. The targeting strategies x_A^* and x_B^* are chosen as simultaneous best responses. I apply the first-order condition on π_{A2} with respect to x_A and to π_{B2} with respect to x_B, and I find:

$$x_A^* = x_B^* = \frac{1}{3}.$$

As $p_{A2}^* = p_{B2}$, the indifferent consumer in period 2 is located at $\tilde{x}_2 = \frac{1}{2}$.

By replacing x_A^* and x_B^* into π_{A2} and π_{B2} I obtain:

$$\pi_{\theta 2}^* = \frac{7t}{18}.$$

Optimal targeting strategies: constrained.

I derive the optimal targeting strategy x_B^* of Firm B when Firm A is constrained and $x_A^* = \tilde{x}_1$.

x_B^* is chosen as a best response to $x_A^* = \tilde{x}_1$. The profits of the firms are the following:

$$\pi_{A2} = \frac{t}{2} - \frac{7}{9}\tilde{x}_1^2 t + \frac{2}{9}x_B^2 t - \frac{4}{9}\tilde{x}_1 x_B t + \frac{2}{3}\tilde{x}_1 t - \frac{2}{3}x_B t.$$
$$\pi_{B2} = \frac{t}{2} - \frac{7}{9}x_B^2 t + \frac{2}{9}\tilde{x}_1^2 t - \frac{4}{9}x_B \tilde{x}_1 t + \frac{2}{3}x_B t - \frac{2}{3}\tilde{x}_1 t.$$

I apply first-order conditions on π_{B2} with respect to x_B:

$$x_B^* = \frac{3}{7} - \frac{2\tilde{x}_1}{7}.$$

Replacing x_A^* and x_B^* into p_{A2}^* and p_{B2}^*, I find that the indifferent consumer in period 2 is located at $\tilde{x}_2 = \frac{6\tilde{x}_1 + 5}{14}$.

By replacing x_A^* and x_B^* by their expressions into π_{A2} and π_{B2} I obtain:

$$\pi_{A2}^* = \frac{25t}{98} + \frac{30t}{49}\tilde{x}_1 - \frac{31t}{49}\tilde{x}_1^2,$$
$$\pi_{B2}^* = \frac{9t}{14} - \frac{6t}{7}\tilde{x}_1 + \frac{2t}{7}\tilde{x}_1^2.$$

A.3. Proof of Proposition 3

I show that the only equilibrium of the game is symmetric. In the previous proof, prices and targeting strategies in the symmetric case are computed as simultaneous best responses, deviation is not profitable and these strategies constitute an equilibrium.

I now show that the constrained, asymmetric strategy when Firm B undercuts prices is not sustainable, as a firm willing to constrain its competitor by undercutting prices always benefits from deviating to the symmetric equilibrium.

Profits in the symmetric equilibrium are equal to $\frac{7t}{18}$ in period 2 and $\frac{t}{2}$ in period 1 and overall, the payoff of firms in the symmetric equilibrium is $\delta\frac{7t}{18} + \frac{t}{2}$.

I provide an upper bound to the profits of a firm adopting a constraining strategy. The maximal profit in period 2 in the constrained case is reached when $\tilde{x}_1 = 0$ (when Firm A is constrained) and is equal to $\frac{9t}{14}$.

For Firm B to constrain Firm A in period 1, it must be the case that $\tilde{x}_1 \le \frac{1}{3}$. Let us consider the least constraining case where $\tilde{x}_1 = \frac{1}{3}$, which leads to the highest profits of Firm B among the set of constraining strategies in period 1.

The indifferent consumer in the first period is characterized by $\tilde{x}_1 = \frac{p_{B1}-p_{A1}+t}{2t}$, and the profits of the firms are equal to:

$$\pi_{A1}(p_{A1}, p_{B1}) = p_{A1}\frac{p_{B1} - p_{A1} + t}{2t},$$
$$\pi_{B1}(p_{B1}, p_{A1}) = p_{B1}\frac{p_{A1} - p_{B1} + t}{2t}.$$

So that prices can be written as best responses:

$$p_{A1}^* = \frac{p_{B1}^* + t}{2}, \quad p_{B1}^* = \frac{p_{A1}^* + t}{2}.$$

And the location of the indifferent consumers can be written:

$$\tilde{x}_1 = \frac{p_{B1}^* - \frac{p_{B1}^*+t}{2} + t}{2t} = \frac{p_{B1}^* + t}{4t}.$$

To obtain $\tilde{x}_1 = \frac{1}{3}$, Firm B must charge $p_{B1}^* = \frac{t}{3}$ yielding profits in period 1 equal to $\frac{2t}{9}$.

Thus the sum of profits over both periods in the constraining case is therefore lower than $\frac{2t}{9} + \delta\frac{9t}{14} < \frac{t}{2} + \delta\frac{7t}{18}$, and profits are higher in the symmetric equilibrium.

Hence deviation is profitable, asymmetric pricing is not sustainable, and the only equilibrium of the game is symmetric.

A.4. Proof of Proposition 4

Unconstrained equilibrium:

I compare the utility of consumers located at $x \in [0, \frac{1}{3}]$ when purchasing their preferred product with their utility from purchasing Firm B's product in period 1 and paying the homogeneous price in period 2.

The utility when purchasing from Firm A is $u_1(x) = V - tx - t$ in period 1 and $u_2(x) = V - tx - \frac{4t}{3} + 2tx$ in period 2.

The utility when purchasing from Firm B in period 1 is $u_{1B}(x) = V - t(2 - x)$ and $u_{2A}(x) = V - tx - \frac{t}{3}$ when paying the homogeneous price in period 2.

For all $\delta_c \le 1$, $u_1(x) + \delta_c u_2(x) \ge u_{1B}(x) + \delta_c u_{2A}(x)$ and consumers do not hide.

Constrained case:

In the constrained case we show that some consumers may have interest to hide from Firm A but not from Firm B. Then, we show that adopting a constraining strategy when consumers are forward looking is still dominated by the symmetric equilibrium. To do so, we solve the game with forward-looking consumers in the case where they have the greatest incentives to hide, i.e. when $\delta_c = 1$.

Remember that in the constrained case, the numbers of consumers identified by each firm are equal to:

$$x_A^* = \tilde{x}_1, \quad x_B^* = \frac{3}{7} - \frac{2\tilde{x}_1}{7}.$$

Moreover, we have shown that the prices paid by targeted consumers in the second stage are equal to:

$$p_{A2}(x) = 2t - \frac{4t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) - \frac{2t}{3}\tilde{x}_1 - 2tx,$$
$$p_{B2}(x) = 2tx - \frac{4t}{3}\tilde{x}_1 - \frac{2t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right).$$

Consumers do not hide from Firm B. Consumers located at $x \in [1 - x_B^* = \frac{4}{7} + \frac{2\tilde{x}_1}{7}, 1]$ can decide to purchase from Firm A in the first period to benefit from the homogeneous price in the second period. Doing so, they pay the following prices and obtain the following utilities:

$$p_{A1} = 2t\tilde{x}_1 \implies u(x) = V - 2t\tilde{x}_1 - tx,$$
$$p_{B2} = t[1 - \frac{2}{3}\tilde{x}_1 - \frac{4}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right)] \implies u(x) = V - p_{B2} - t(1 - x)$$

The alternative for these consumers is to purchase from Firm B at both periods, and have the following prices and utilities:

$$p_{B1} = 4t\tilde{x}_1 - t \implies u(x) = V - 4t\tilde{x}_1 + t - t(1 - x),$$
$$p_{B2}(x) = 2tx - \frac{4t}{3}\tilde{x}_1 - \frac{2t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) \implies u(x) = V - p_{B2}(x) - t(1 - x).$$

We take the difference of the sum of utilities over both periods:

$$V - 2t\tilde{x}_1 - tx + \delta_c\left[V - t[1 - \frac{2}{3}\tilde{x}_1 - \frac{4}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right)] - t(1 - x)\right]$$
$$> V - 4t\tilde{x}_1 + t - t(1 - x) + \delta_c$$
$$\times\left[V - \left(2tx - \frac{4t}{3}\tilde{x}_1 - \frac{2t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right)\right) - t(1 - x)\right]$$

This inequality always holds as $\tilde{x}_1 \le \frac{1}{3}$.

Some consumers hide from Firm A.

Consumers located at $x \in [0, \tilde{x}_1]$ can either purchase from Firm A at both competition stages and pay prices:

$$p_{A1} \implies u(x) = V - p_{A1} - tx,$$
$$p_{A2}(x) = 2t - \frac{4t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) - \frac{2t}{3}\tilde{x}_1 - 2tx \implies u(x) = V - p_{A2}(x) - tx.$$

Or purchase from Firm B at the first stage and pay prices equal to:

$$p_{B1} \implies u(x) = V - p_{B1} - t(1 - x),$$
$$p_{A2} = t - \frac{2t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) - \frac{4t}{3}\tilde{x}_1 \implies u(x) = V - p_{A2} - tx.$$

Taking the difference of the sum of utilities over both periods allows us to find the location of the indifferent forward-looking consumer:

$$V - p_{A1} - tx + \delta_c\left[V - \left(2t - \frac{4t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) - \frac{2t}{3}\tilde{x}_1 - 2tx\right) - tx\right]$$
$$= V - p_{B1} - t(1 - x) + \delta_c\left[V - \left(t - \frac{2t}{3}\left(\frac{3}{7} - \frac{2\tilde{x}_1}{7}\right) - \frac{4t}{3}\tilde{x}_1\right) - tx\right]$$
$$\iff p_{B1} - p_{A1} + t - 2t\tilde{x}_1 + \delta_c\left[-\frac{5t}{7} + \frac{8t}{7}\tilde{x}_1\right] = 0$$

$$\iff \tilde{x}_1 = 6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}$$

Firms do not benefit to adopt constraining strategies.

The profits of the firms when Firm B engages in a constraining strategy with forward-looking consumers are equal to:

$$\pi_{A1} + \pi_{A2} = p_{A1}\left(6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}\right)$$
$$+\frac{25t}{98} + \frac{30t}{49}\left(6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}\right) - \frac{31t}{49}\left(6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}\right)^2$$
$$\pi_{B1} + \pi_{B2} = p_{B1}\left(6\frac{p_{A1} - p_{B1}}{7t} + \frac{2}{3}\right)$$
$$+\frac{9t}{14} - \frac{6t}{7}\left(6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}\right) + \frac{2t}{7}\left(6\frac{p_{B1} - p_{A1}}{7t} + \frac{1}{3}\right)^2$$

Solving for the equilibrium best responses we find

$$p_{A1} = \frac{1640t}{11097}, \quad p_{B1} = \frac{2741t}{22194},$$

and profits are equal to:

$$\pi_{A1} + \pi_{A2} = \frac{35369731t}{82095606}, \quad \pi_{B1} + \pi_{B2} = \frac{20022944t}{41047803}.$$

We can conclude that constraining strategies are dominated with forward-looking consumers by showing that the profits of Firm B $\frac{20022944t}{41047803}$ (and in turn for Firm A) are below profits in the symmetric equilibrium: $\frac{t}{2} + \frac{7t}{18}$.

Appendix B. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.infoecopol.2024.101081.

References

Acemoglu, D., 2021. Harms of ai. Technical report. National Bureau of Economic Research.

Acquisti, A., Varian, H.R., 2005. Conditioning prices on purchase history. Mark. Sci. 24 (3), 367–381.

Anderson, S.P., Renault, R., 2009. Comparative advertising: disclosing horizontal match information. Rand J. Econ. 40 (3), 558–581.

Asplund, M., Eriksson, R., Strand, N., 2008. Price discrimination in oligopoly: evidence from regional newspapers. J. Ind. Econ. 56 (2), 333–346.

Belleflamme, P., Lam, W.M.W., Vergote, W., 2020. Competitive imperfect price discrimination and market power. Mark. Sci. 39 (5), 996–1015.

Bertini, M., Koenigsberg, O., 2021. The pitfalls of pricing algorithms: be mindful of how they can hurt your brand. Harv. Bus. Rev. 99 (5), 74–83.

Bisceglia, M., Padilla, J., 2023. On sellers' cooperation in hybrid marketplaces. J. Econ. Manag. Strategy 32 (1), 207–222.

Bounie, D., Dubus, A., Waelbroeck, P., 2021. Selling strategic information in digital competitive markets. Rand J. Econ. 52 (2), 283–313.

Brown, Z.Y., MacKay, A., 2023. Competition in pricing algorithms. Am. Econ. J. Microecon. 15 (2), 109–156.

Calvano, E., Calzolari, G., Denicolo, V., Pastorello, S., 2020. Artificial intelligence, algorithmic pricing, and collusion. Am. Econ. Rev. 110 (10), 3267–3297.

Chen, Y., Pearcy, J., 2010. Dynamic pricing: when to entice brand switching and when to reward consumer loyalty. Rand J. Econ. 41 (4), 674–685.

Chen, Z., Choe, C., Matsushima, N., 2020. Competitive personalized pricing. Manag. Sci. 66 (9), 4003–4023.

Choe, C., King, S., Matsushima, N., 2018. Pricing with cookies: behavior-based price discrimination and spatial competition. Manag. Sci. 64 (12), 5669–5687.

Choudhary, V., Ghose, A., Mukhopadhyay, T., Rajan, U., 2005. Personalized pricing and quality differentiation. Manag. Sci. 51 (7), 1120–1130.

Corts, K.S., 1998. Third-degree price discrimination in oligopoly: all-out competition and strategic commitment. Rand J. Econ., 306–323.

DalleMule, L., Davenport, T.H., 2017. What's your data strategy. Harv. Bus. Rev. 95 (3), 112–121.

Du, R.Y., Netzer, O., Schweidel, D.A., Mitra, D., 2021. Capturing marketing information to fuel growth. J. Mark. 85 (1), 163–183.

Eschenbaum, N., Mellgren, F., Zahn, P., 2022. Robust algorithmic collusion. ArXiv preprint. arXiv:2201.00345.

Esteves, R.-B., Liu, Q., Shuai, J., 2022. Behavior-based price discrimination with nonuniform distribution of consumer preferences. J. Econ. Manag. Strategy 31 (2), 324–355.

Fudenberg, D., Tirole, J., 2000. Customer poaching and brand switching. Rand J. Econ., 634–657.

Fudenberg, D., Villas-Boas, J.M., 2006. Behavior-based price discrimination and customer recognition. In: Handbook on Economics and Information Systems, vol. 1, pp. 377–436.

Gautier, A., Ittoo, A., Van Cleynenbreugel, P., 2020. Ai algorithms, price discrimination and collusion: a technological, economic and legal perspective. Eur. J. Law Econ. 50 (3), 405–435.

Gorodnichenko, Y., Sheremirov, V., Talavera, O., 2018. Price setting in online markets: does it click? J. Eur. Econ. Assoc. 16 (6), 1764–1811.

Hansen, K.T., Misra, K., Pai, M.M., 2021. Frontiers: algorithmic collusion: supracompetitive prices via independent algorithms. Mark. Sci. 40 (1), 1–12.

Hinz, O., Hann, I.-H., Spann, M., 2011. Price discrimination in e-commerce? An examination of dynamic pricing in name-your-own price markets. MIS Q., 81–98.

Ioannidou, V., Ongena, S., 2010. "Time for a change": loan conditions and bank behavior when firms switch banks. J. Finance 65 (5), 1847–1877.

Jentzsch, N., Sapi, G., Suleymanova, I., 2013. Targeted pricing and customer data sharing among rivals. Int. J. Ind. Organ. 31 (2), 131–144.

Klein, T., 2018. Assessing autonomous algorithmic collusion: Q-learning under short-run price commitments. Technical report, Tinbergen Institute Discussion Paper.

Lee, D.-J., Ahn, J.-H., Bang, Y., 2011. Managing consumer privacy concerns in personalization: a strategic analysis of privacy protection. MIS Q., 423–444.

Li, K.J., Jain, S., 2016. Behavior-based pricing: an analysis of the impact of peer-induced fairness. Manag. Sci. 62 (9), 2705–2721.

Liu, Q., Serfes, K., 2004. Quality of information and oligopolistic price discrimination. J. Econ. Manag. Strategy 13 (4), 671–702.

Liu, Q., Serfes, K., 2007. Market segmentation and collusive behavior. Int. J. Ind. Organ. 25 (2), 355–378.

Loots, T., den Boer, A.V., 2023. Data-driven collusion and competition in a pricing duopoly with multinomial logit demand. Prod. Oper. Manag. 32 (4), 1169–1186.

Matsumura, T., Matsushima, N., 2015. Should firms employ personalized pricing? J. Econ. Manag. Strategy 24 (4), 887–903.

McSweeny, T., O'Dea, B., 2017. The implications of algorithmic pricing for coordinated effects analysis and price discrimination markets in antitrust enforcement. Antitrust 32, 75.

Mehra, A., Bala, R., Sankaranarayanan, R., 2012. Competitive behavior-based price discrimination for software upgrades. Inf. Syst. Res. 23 (1), 60–74.

Montes, R., Sand-Zantman, W., Valletti, T., 2019. The value of personal information in online markets with endogenous privacy. Manag. Sci. 65 (3), 1342–1362.

Peiseler, F., Rasch, A., Shekhar, S., 2022. Imperfect information, algorithmic price discrimination, and collusion. Scand. J. Econ. 124 (2), 516–549.

Salcedo, B., 2015. Pricing algorithms and tacit collusion. Pennsylvania State University. Manuscript.

Shiller, B.R., et al., 2013. First Degree Price Discrimination Using Big Data. Brandeis Univ., Department of Economics.

Stole, L.A., 2007. Price discrimination and competition. In: Handbook of Industrial Organization, vol. 3, pp. 2221–2299.

Thiel, J.H., 2019. Price discrimination, switching costs and welfare: evidence from the Dutch mortgage market.

Thisse, J.-F., Vives, X., 1988. On the strategic choice of spatial price policy. Am. Econ. Rev., 122–137.

Ulph, D., Vulkan, N., 2000. Electronic Commerce and Competitive First-Degree Price Discrimination. University of Bristol, Department of Economics.

Villas-Boas, J.M., 1999. Dynamic competition with customer recognition. Rand J. Econ., 604–631.

Villas-Boas, J.M., 2004. Price cycles in markets with customer recognition. Rand J. Econ., 486–501.

Wang, X., Li, X., Kopalle, P.K., 2022. When does it pay to invest in pricing algorithms? Prod. Oper. Manag.