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Qiuyu Lu, Noriaki Matsushima, Shiva Shekhar

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Welfare Implications of Personalized Pricing in Competitive Platform Markets: The Role of Network Effects

Abstract

This study explores the welfare impact of personalized pricing for consumers in a duopolistic two-sided market, with consumers single-homing and developers affiliating with a platform according to their outside option. Personalized pricing, which is private in nature, cannot influence expectations regarding the network sizes, inducing the platforms to offer lower participation fees for developers. Those lower fees increase network benefits for consumers, allowing the platforms to exploit these benefits through personalized pricing. Personalized prices are higher when the network value for developers is high, benefiting competing platforms at the expense of consumers. These findings offer policy insights on personalized pricing.

JEL-Codes: L130, D430.

Keywords: personalized pricing, uniform prices, two-sided market, content developers.

Qiuyu Lu
Graduate School of Economics
Osaka University / Japan
newssdukeloo@gmail.com

*Noriaki Matsushima**
Institute of Social and Economic Research
Osaka University / Japan
nmatsush@iser.osaka-u.ac.jp

Shiva Shekhar
Tilburg School of Economics and Management
Tilburg University / The Netherlands
shiva.shekhar.g@gmail.com

*corresponding author

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1 Introduction

Two primary trends are discernible alongside the growing maturity of complementary technologies in digital markets. First, firms recognize the inherent value in cross-side network benefits and are increasingly adopting the platform business model by extending their product offerings to third-party creators. Second, firms are progressively utilizing sophisticated tools to track consumers.[1] The implementation of sophisticated data analytics tools in consumer tracking enhances the value for firms, enabling a deeper understanding of consumer needs, preferences, and willingness to pay. Consequently, we observe digital multi-sided firms resorting to personalized pricing. This practice enables the better extraction of consumer surplus (Wagner and Eidenmüller, 2019). Notably, recent studies by Shiller (2020), Dubé and Misra (2023), and Smith et al. (2023) have provided quantitative evidence supporting the effectiveness of such practices. In this technology-driven market landscape, it is important to understand how these technologies and pricing schemes interact and their impact on welfare

The extant literature on the effects of competitive personalized pricing by firms on their profits and consumers is ambiguous. A vast body of literature posits that personalized pricing is detrimental for firms compared to uniform pricing in oligopoly markets (Thisse and Vives, 1988, Shaffer and Zhang, 1995, Zhang, 2011). However, this view is challenged by the increased prevalence of personalized prices adopted by (competing) platform firms. In addition, some recent works suggest that personalized pricing may not consistently yield negative consequences for firms (e.g., Shaffer and Zhang, 2002, Choudhary et al., 2005, Matsumura and Matsushima, 2015, Esteves and Shuai, 2022). In our paper, we present a mechanism that helps reconcile these contrasting viewpoints and observations on the impact of personalized pricing on firm profitability and consumers in the presence of network benefits.

Towards this, we examine the effect of personalized pricing in a two-sided market in which content developers and consumers interact in platform firms. An apt illustration of

[1]Firms leverage data collected from personal devices such as smartphones and smartwatches, a reality facilitated by digitization (e.g., European Commission, 2018, OECD, 2018, Ofcom, 2020).

such markets includes online platforms such as UberEats that offer personalized discounts on purchases linked to your account.[2] Similarly, the Dutch Competition Ombudsman (Authority for Consumers and Markets (ACM)) found that Wish, an online e-commerce firm, engaged in personalized pricing.[3] Given the prevalence of such pricing schemes in platform markets, engaging in a discussion about personalized pricing in a two-sided market is an academic as well as a policy-relevant endeavor

In a model where competing multi-sided firms attract developers (complementors) and consumers, we show that personalized pricing charged to consumers benefits developers and can benefit competing firms vis-à-vis uniform prices. Under competition, it is well-known that personalized pricing enhances firm competition for consumers. As these firms are multi-sided, this increased competition encourages firms to lower developer fees to increase consumers' expectations for the value of interacting with developers. This directly benefits developers. Thus, one would expect that firm profits fall under personalized prices. Interestingly, we find that firm profits rise when the developers' network interaction value is high. This is because employing personalized pricing also has a competition-dampening effect, given that personalized prices are privately offered and do not affect the developers' expectations for consumer network size. Consequently, these consumer prices are less sensitive to changes in developers' network interaction value.

As we focus on two-sided platforms, under uniform pricing, consumer price falls as the developers' interaction value rises.[4] Thus, when the developers' interaction value is high, consumer prices under personalized pricing are higher than under uniform pricing because consumer prices (under personalized pricing) are less sensitive to changes in developers'

[2]Furthermore, the Austrian Arbeiterkammer (AK - Chamber of Labour) concluded in 2019 that different flight and hotel booking websites showed varying prices depending on whether a computer or a mobile device was used to access the website (see link). More detailed discussions on the prevalence of personalized pricing can be found in a study commissioned by the European Parliament (Rott et al. (2022)). Another example is online subscription-based video-on-demand services. In this context, leading companies like Netflix provide users with personalized recommendations (Kim et al., 2017). The capability to deliver such personalized recommendations suggests that Netflix potentially incorporates personalized pricing into its strategy, as discussed by Shiller (2020). We can extend this thinking to Amazon Prime Video, which similarly excels in providing personalized recommendations.

[3]See Bourreau and De Streel (2018) and Rott et al. (2022) for more instances of personalized pricing.

[4]See Rochet and Tirole (2003), Parker and Van Alstyne (2005), Armstrong (2006), Rochet and Tirole (2006), Jullien (2011).

network interaction value. This results in platform profit rising despite lower developer fees. This novel and counterintuitive result on the impact of personalized pricing in our paper is elicited solely due to cross-sided network effects. Note that the consumers' network interaction value is not influential because personalized pricing does not influence developer fees as much. Finally, we find that the total surplus is unambiguously higher under personalized pricing.

The rest of the paper is organized as follows. In Section 2, we discuss the related literature. Following that, in Section 3, we lay down the model. The analysis is presented in Section 4, where we first discuss the outcome under uniform pricing, then explore the outcome under price discrimination, and finally delve into the welfare effects of personalized pricing. We conclude in Section 6. Proofs are relegated to the Appendix.

2 Related Literature

Our study contributes to the extensive literature on two-sided markets (e.g., Caillaud and Jullien, 2003, Rochet and Tirole, 2003, Parker and Van Alstyne, 2005, Armstrong, 2006, Rochet and Tirole, 2006, Jullien, 2011). In contrast to previous research where uniform prices were charged to consumers, we enhance this stream of literature by incorporating the ability of firms to set personalized consumer prices – a relevant feature of today's digital market – and analyzing the resulting outcomes.

We also contribute to the extant literature that discusses the effect of personalized pricing under competition (e.g., Thisse and Vives, 1988, Shaffer and Zhang, 2002, Choe et al., 2018, Esteves and Shuai, 2022, Houba et al., 2023, Rhodes and Zhou, 2022). With the exception of Rhodes and Zhou (2022), all the other works show that personalized pricing under competition leads to an increase in consumer surplus at the expense of firms. Rhodes and Zhou (2022) qualifies the conditions under which the consumer surplus-increasing results in Thisse and Vives (1988) hold. They find that the welfare results in Thisse and Vives (1988) hold only when market coverage is high. Related to Rhodes and Zhou (2022), Lu and Matsushima (2023) also show that personalized pricing harms consumer surplus in a Hotelling duopoly model with multi-item purchasing if the additional utility from the second item is high and consumers are more likely to purchase from both firms. In our work, we elucidate the conditions under which personalized pricing can lower consumer surplus even under full market coverage, as in Thisse and Vives (1988). The novelty of our results is a direct consequence of the presence of network effects, which are absent in Rhodes and Zhou (2022). Specifically, the private nature of personalized pricing schemes implies they are not used in aiding expectation formation. This lowers competition intensity vis-à-vis uniform (public) consumer prices.

Focusing on price discrimination in markets featuring network effects, two closely related papers investigate the effect of personalized pricing in two-sided markets: Liu and Serfes (2013) and Kodera (2015). Liu and Serfes (2013) compare the profits of two platform firms under uniform and personalized pricing in the duopolistic two-sided market described by Armstrong (2006). They consider the case where the platforms employ personalized pricing on both sides, differing from ours (which focuses only on the consumer side). They show that personalized pricing is better for the platforms if and only if the sum of the degree of cross-market externality on consumers and that on participating firms is higher than a threshold value.[5] In contrast to their paper, we consider a competitive bottleneck model where consumer-side single-homing and developers' demands are elastic. This difference in market structure elicits interesting welfare results, demonstrating that personalized pricing leads to increased developer participation (and their welfare) as well as higher total welfare.

Finally, as personalized prices are private and not observed by developers, our work also advances the strand of literature on how information announcements (including pricing information) in platform markets aid in forming expectations regarding network benefits. Hagiu and Hałaburda (2014) find that competing platforms may prefer not to reveal information, including pricing details, to lower competition.[6] Belleflamme and Peitz (2019) generalize the model of Hagiu and Hałaburda (2014) and additionally find that results

[5]Kodera (2015) extends Liu and Serfes (2013) by replacing firms in Liu and Serfes (2013) with advertisers that cause negative externality on consumers. He also assumes that the platforms exert personalized pricing only on the advertiser side. He shows that personalized pricing is better for the platforms only if the degree of negative externality on consumers is sufficiently large.

[6]A related work where users cannot observe fees is Ding and Wright (2017).

depend on the single- or multi-homing decisions of the two sides and competitive intensity. Similarly, Chellappa and Mukherjee (2021) find that pre-announcement to inform market expectations can be profitable for firms and depend on the competitive intensity. In contrast to these works, information revelation levels in our setting are affected due to the private nature of personalized pricing. Our work bridges the results in these two different streams of literature and elicits novel results that are counterintuitive to the established findings in each piece of literature.

3 Model

We consider a market setting with two competing multi-sided firms denoted by $i = 1, 2$ that connect consumers and developers. On the consumer side, firms 1 and 2 are at the edges of a Hotelling line, with $x_1 = 0$ and $x_2 = 1$, respectively. The uniform pricing benchmark model is identical to that in (Hagiu and Hałaburda, 2014, Section 4.1), and differs from it in the personalized pricing regime.[7]

Consumers are distributed according to their relative preference x for firm 2 over firm 1. This preference x follows a uniform distribution with unit support, i.e., $x \sim \mathcal{U}[0, 1]$. A consumer of type x incurs a mismatch cost of tx and $t(1-x)$ when transacting, respectively, at firms 1 and 2, where t is a positive constant representing the degree of preference mismatch.[8] The utility of a consumer of type x when purchasing firm 1's product or firm 2's product is given as:

$$U_1(p_1, D_1^e, x) = w + \theta D_1^e - p_1 - tx, \quad \text{purchasing from firm 1,} \tag{1}$$

$$U_2(p_2, D_2^e, x) = w + \theta D_2^e - p_2 - t(1 - x), \quad \text{purchasing from firm 2,} \tag{2}$$

where $w(> 0)$ is the common intrinsic utility that a consumer enjoys from the consumption of the product. Additionally, θD_i^e represents the expected value consumers derive from interacting with developers, where D_i^e is the expected mass of developers at firm i, and θ

[7] Reisinger (2012) considers a media competition in a similar framework.

[8] The parameter t is often used as a proxy for a lack of competition. Specifically, as t increases, competition between the two firms becomes less intense, as consumers closer to one firm find the product of the other firm relatively less valuable to consider.

is the interaction value consumers place on interaction with each additional developer at firm i. Furthermore, p_i is the consumer price charged by firm i. Here, the superscript e indicates consumers' expectations for the mass of developers at firm i. Thus, θD_i^e reflects the cross-market network benefit enjoyed by consumers.

Developers in our setting are distributed according to their outside option k, which follows a uniform distribution with unit support, i.e., $k \sim \mathcal{U}[0,1]$. These developers value interactions with consumers in a firm. The payoff of a developer of type k interacting with consumers at firm $i \in 1, 2$ is

$$\pi_i^{Dev}(l_i, N_i^e, k) = \phi N_i^e - l_i - k,$$

where ϕ is the interaction value developers place on interacting with an additional consumer, N_i^e is the expected mass of consumers at firm i, and l_i is the participation fee charged by firm i to developers for interacting with its consumers.

The profit of each firm i is a composite term of consumer sales revenues and developer sales revenues and is given as

$$\Pi_i = \underbrace{p_i N_i}_{\substack{\text{Consumer} \\ \text{sales revenue}}} + \underbrace{l_i D_i.}_{\substack{\text{Developer} \\ \text{sales revenue}}}$$

We consider two consumer pricing regimes employed by firms: (i) uniform pricing and (ii) personalized pricing. In case (ii), firms can perfectly identify the locations of all consumers and offer personalized prices to them. That is, prices become a function of consumer types x and are denoted as $p_i(x)$.

We assume that detecting each developer's outside value is challenging for the firms because they need information about developers' outside opportunities related to *outside* markets in which those developers can be active. The nature of such information differs from consumer preferences related to the *inside* market activities. The difficulty of gathering outside information prevents the firms from offering personalized fees to those developers.

The timing of the game is as follows:

(1.) Firms simultaneously offer prices p_i and fees l_i to consumers and developers, respectively. When firms employ personalized pricing, we replace p_i with $p_i(x)$.

(2.) Consumers and developers, respectively, form expectations for the masses of developers and consumers in each firm and then decide to affiliate with firms. Subsequently, profits are realized.

We impose the following technical restrictions.

Assumption 1. *(i) The intrinsic value is high enough — i.e.,* $w \geq 3t/2$. *(ii) The exogenous parameters,* t, θ, *and* ϕ, *satisfy* $t > \underline{t} \equiv \max\{(\theta^2 + 6\theta\phi + \phi^2)/8, \theta(\theta + 6\phi + \sqrt{\theta^2 + 12\theta\phi + 4\phi^2})/8\}$.

The first restriction ensures that the market is covered and each consumer purchases at one of the firms. The second assumption ensures that the second-order conditions are satisfied in both pricing regimes.

4 Analysis

We consider two cases in which firms employ the following pricing schemes on the consumer side: (i) uniform pricing and (ii) personalized pricing. We then compare the outcomes in the two cases and present the welfare results.

4.1 Uniform pricing

In stage 2, we first derive the demand functions to formulate the objectives of the firms. Observing the prices set in stage 1, consumers and developers form expectations D_i^e and N_i^e and then participate in firm i.

From equations (1) and (2), we derive the location of indifferent consumers denoted by $\bar{x}$, which provides us with the mass of consumers at firm 1 and firm 2 as:

$$N_1(D_1^e, D_2^e, p_1, p_2) = \bar{x} = \frac{t + \theta(D_1^e - D_2^e) - p_1 + p_2}{2t}, \; N_2(\cdot) = 1 - \bar{x}. \tag{3}$$

The above demands are intuitive: as the consumer price set by firm i rises, their demand for the product of firm i falls. Conversely, as the price set by the rival firm $-i$ increases, the demand at firm i rises. Additionally, as the expectation of the value from developer interaction (θD_i^e) increases, consumer demand at firm i rises as well.

Developers participate on the platform as long as they enjoy positive payoffs, i.e., $\pi_i^{Dev}(\cdot) \geq 0$. Solving this inequality yields the indifferent consumer type's outside option denoted by $\bar{k}_i$, below which developers find it profitable to participate on firm i. Thus, we can express the mass of developers active on firm i as:

$$D_i(N_i^e, l_i) = \bar{k}_i(N_i^e, l_i) = \phi N_i^e - l_i. \tag{4}$$

Because we employ a fulfilled expectations equilibrium, the expected mass of developers and consumers must match the realized demands. By imposing $N_i^e = N_i^\star$ and $D_i^e = D_i^\star$ in equations (3) and (4) and solving for the mass of consumers and the mass of developers on two firms, we obtain demands as a function of fees, as presented below for ($i = 1, 2$):

$$\begin{aligned} N_i^\star(p_i, p_{-i}, l_i, l_{-i}) &= \frac{1}{2} - \frac{(p_i - p_{-i}) + \theta(l_i - l_{-i})}{2(t - \theta\phi)}, \\ D_i^\star(l_i, l_{-i}, p_i, p_{-i}) &= \frac{\phi}{2} - \frac{\phi(p_i - p_{-i}) + (2t - \theta\phi)l_i - \theta\phi l_{-i}}{2(t - \theta\phi)}. \end{aligned} \tag{5}$$

As the consumer price or developer fee at firm i increases, both consumer and developer participation falls. This is because, apart from lowering the direct value of participation on firm i, a higher (consumer or developer) price also lowers the expected value of interactions on the other side. Furthermore, the equations in (5) show that as the degree of network benefits rises, demands become more price-elastic.

In stage 1, each firm $i \in \{1, 2\}$ sets prices and fees to maximize its profits, given as

$$\max_{l_i, p_i} \Pi_i(p_i, p_{-i}, l_i, l_{-i}) = p_i N_i^\star(\cdot) + l_i D_i^\star(\cdot).$$

Differentiating the profit of each firm $i \in 1, 2$ with respect to p_i yields the following first-order condition.

$$\underbrace{N_i^\star(\cdot) + p_i \frac{\partial N_i(\cdot)}{\partial p_i}}_{\substack{\text{Volume+} \\ \text{Margin effect}}} + \underbrace{p_i \left[\frac{\partial N_i(\cdot)}{\partial D_i^e} \frac{\partial D_i^\star(\cdot)}{\partial p_i} + \frac{\partial N_i(\cdot)}{\partial D_{-i}^e} \frac{\partial D_{-i}^\star(\cdot)}{\partial p_i} \right]}_{\text{Consumer participation effect } (-)} + \underbrace{l_i \frac{\partial D_i(\cdot)}{\partial N_i^e} \frac{\partial N_i^\star(\cdot)}{\partial p_i}}_{\substack{\text{Developer participation} \\ \text{effect } (-)}} = 0. \tag{6}$$

The above first-order condition describes the marginal impact of an increase in consumer price on the profitability of firm i. The first two terms represent the classical volume and margin effects

The second effect demonstrates how a unit (consumer) price increase affects consumers' participation through changes in their expectations regarding developer participation. Specifically, an increase in price p_i lowers consumers' expectations regarding the participation of developers on platform i. Similarly, consumers' expectations regarding developer participation at the rival platform $-i$ increase. These two effects reinforce each other and lower consumer demand at platform i with a unit increase in price p_i, arising because platforms directly compete for consumers.

The final expression represents how a unit increase in consumer price affects developer participation on the platform through changes in their expectations of the value derived from consumer participation. Specifically, an increase in the price p_i lowers developers' expectations regarding the participation of consumers on platform i, subsequently reducing their own participation as well. A direct consequence of these reinforcing effects, which lower firm profitability, is that firms will compete more fiercely when setting consumer prices, compared to the case without network effects.

Differentiating the profit of each firm $i \in 1, 2$ with respect to l_i yields the following first-order condition.

$$\underbrace{D_i^\star(\cdot) + l_i \frac{\partial D_i(\cdot)}{\partial l_i}}_{\substack{\text{Margin+} \\ \text{Volume effect}}} + \underbrace{p_i \left[\frac{\partial N_i(\cdot)}{\partial D_i^e} \frac{\partial D_i^\star(\cdot)}{\partial l_i} + \frac{\partial N_i(\cdot)}{\partial D_{-i}^e} \frac{\partial D_{-i}^\star(\cdot)}{\partial l_i} \right]}_{\text{Consumer participation effect } (-)} + \underbrace{l_i \frac{\partial D_i(\cdot)}{\partial N_i^e} \frac{\partial N_i^\star(\cdot)}{\partial l_i}}_{\substack{\text{Developer participation} \\ \text{effect } (-)}} = 0. \tag{7}$$

As in the above, a similar discussion regarding the impact of a unit increase in developer participation fees on the profitability of the platforms can be easily made.

Solving the system of first-order conditions in equations (6) and (7) yields the equilibrium fees, as presented below.

$$p_i^U = t - \frac{\phi(3\theta + \phi)}{4}, \quad l_i^U = \frac{\phi - \theta}{4}. \tag{8}$$

First, note that, in comparison to a traditional Hotelling model without network effects, the uniform consumer price is lower. This is due to network effects, which encourage firms to set low consumer prices unilaterally. Furthermore, recalling that prices are strategic complements, the rival firm also lowers prices, resulting in fiercer competition with increased value from network effects. On the developer side, given that each firm has monopoly power over developers, an increase in the degree of network interaction benefits, ϕ, raises the fee for developers. At the same time, the consumer price, p_i, decreases to enhance the network benefits on developers, ϕN_i. Contrary to the effect of ϕ on fees and prices, as the degree of network benefits on consumers, θ, becomes larger, the fee for developers, l_i , and the consumer price, p_i, decrease due to elastic consumer demand and the incentives to enhance the network benefits on consumers, θD_i.

Substituting the equilibrium fees presented in equation (8) into the calculations for profits, demands, consumer surplus, and producer surplus yields the following outcome:

Lemma 1. *The equilibrium profits, the equilibrium mass of consumers and developers, the equilibrium consumer surplus, and the equilibrium surplus of developers are:*

$$\begin{aligned}
\pi_i^U &= \frac{t}{2} - \frac{\theta^2 + 6\theta\phi + \phi^2}{16}, \quad N_i^U = \frac{1}{2}, \quad D_i^U = \frac{\theta + \phi}{4}, \\
CS^U &= \int_0^{N_1^U} (w + \theta D_1^U - tx - p_1^U)dx + \int_{N_1^U}^1 (w + \theta D_2^U - t(1-x) - p_2^U)dx \\
&= w - \frac{5t}{4} + \frac{\theta^2 + 4\theta\phi + \phi^2}{4}, \\
PS^U &= \int_0^{D_1^U} (\phi N_1^U - k - l_1^U)dk + \int_0^{D_2^U} (\phi N_2^U - k - l_2^U)dk = \frac{(\theta + \phi)^2}{16}.
\end{aligned} \tag{9}$$

Firm profits monotonically decrease with the increase in the values of network interactions θ and ϕ. This is because each firm now independently finds it profitable to expand the network. As firms compete, their strategic interaction leads to accelerated competition. As competition intensifies, both consumer surplus and developer surplus increase with the degree of network benefits, θ and ϕ.

4.2 Personalized pricing

In personalized pricing, the two competing firms can perfectly identify consumers based on their type x and establish individualized pricing schedules.[9].

We assume that personalized prices are kept confidential, known only to the involved parties, and do not influence the expectations developers form regarding consumer participation on firm i (N_i^e for $i = 1, 2$). In reality, disclosing individual trading terms to the public could raise privacy concerns; hence, we make this assumption.

We derive the results when firms can identify consumers and implement personalized pricing. Using the utilities presented in (1) and (2), we obtain the price schedules of firms 1 and 2 when the rival firm sets a zero price. This involves determining the location of indifferent consumers and, consequently, the mass of consumers on firm i:

$$p_1(x) = \begin{cases} \theta(D_1^e - D_2^e) + t(1-2x) & \text{if } x \leq \bar{x}, \\ 0 & \text{if } x > \bar{x}, \end{cases} \tag{10}$$

$$p_2(x) = \begin{cases} 0 & \text{if } x \leq \bar{x}, \\ \theta(D_2^e - D_1^e) + t(2x-1), & \text{if } x > \bar{x}. \end{cases} \tag{11}$$

$$N_1(D_1^e, D_2^e) = \bar{x}(D_1^e, D_2^e) = \frac{t + \theta(D_1^e - D_2^e)}{2t}, \quad N_2(\cdot) = 1 - \bar{x}(\cdot).$$

Considering the fees charged to developers, the expected number of developers must align with the actual number, denoted as $D_i^e = D_i^{\star\star}$ ($i = 1, 2$), under the conditions $N_i^e = N_i^{\star\star}$. Utilizing these conditions, comprising four equations and equation (4), determines that the mass of developers active in each firm i is solely influenced by the developer participation fees.

$$D_i^{\star\star}(l_i, l_{-i}) = \frac{\phi}{2} - \frac{(2t - \theta\phi)l_i - \theta\phi l_{-i}}{2(t - \theta\phi)} \text{ for } i = 1, 2. \tag{12}$$

As in uniform pricing, when the developer fee on firm i increases, developer participation on firm i decreases. Conversely, as the developer fee charged by firm $-i$ rises, consumer demand on firm i increases. This phenomenon occurs because consumers factor in the reduced relative value of interacting with developers on firm $-i$.

[9] This extreme information structure is commonly employed in related works on personalized pricing (e.g., Thisse and Vives, 1988, Shaffer and Zhang, 2002, Esteves and Shuai, 2022)

As consumer prices are not observed and remain private, the mass of developers, denoted as $D_i^{\star\star}(\cdot)$, is independent of these personalized consumer price schedules. Specifically, as prices are confidential and personalized, firms lack the ability to utilize these price schedules to influence the participation of developers. This diminishes competition for consumers, as firms are unable to deploy one of their strategic tools in stage 1 to impact developer participation. The competition mitigation effect resulting from secret (unobserved) consumer prices aligns with the findings in Hagiu and Hałaburda (2014). However, in contrast to Hagiu and Hałaburda (2014), this competition mitigation effect is counteracted by the *competition-enhancing effect* of personalized prices, as discussed in Thisse and Vives (1988). This distinctive aspect of our work introduces nuanced insights into welfare considerations.

By substituting the mass of developers as presented in equation (12), we can derive the actual price schedules and the mass of consumers for firm i as a function of developer fees:

$$p_1^{\star\star}(l_1, l_2, x) = \begin{cases} \dfrac{\theta(l_2 - l_1)t}{t - \theta\phi} + t(1 - 2x) & \text{if } x \leq \bar{x}^{\star\star}, \\ 0 & \text{if } x > \bar{x}^{\star\star}, \end{cases} \tag{13}$$

$$p_2^{\star\star}(l_2, l_1, x) = \begin{cases} 0 & \text{if } x \leq \bar{x}^{\star\star}, \\ \dfrac{\theta(l_2 - l_1)t}{t - \theta\phi} + t(2x - 1), & \text{if } x > \bar{x}^{\star\star}, \end{cases} \tag{14}$$

$$N_1^{\star\star}(l_1, l_2) = \frac{t - \theta\phi + \theta(l_2 - l_1)}{2(t - \theta\phi)}, \quad N_2^{\star\star}(l_2, l_1) = \frac{t - \theta\phi + \theta(l_1 - l_2)}{2(t - \theta\phi)}, \tag{15}$$

where $\bar{x}^{\star\star}(l_1, l_2) = \bar{x}_1(D_1^{\star\star}(\cdot), D_2^{\star\star})$. The price schedules in (13) and (14) suggest that each firm can charge higher personalized prices by reducing its fee to increase the number of developers. The effectiveness of the fee reduction is more pronounced with higher degrees of network benefits, θ.

In stage 1, each firm i strategically determines the value of l_i to maximize its profits.

$$\max_{l_1} \Pi_1^{\star\star} = \int_0^{\bar{x}^{\star\star}} p_1^{\star\star}(l_1, l_2, x)dx + l_1 D_1^{\star\star}(\cdot), \quad \max_{l_2} \Pi_2^{\star\star} = \int_{\bar{x}^{\star\star}}^1 p_2^{\star\star}(l_2, l_1, x)dx + l_2 D_2^{\star\star}(\cdot).$$

Employing the Leibniz integral rule and differentiating the profit of each firm 1 with respect to the fee l_1 yields

$$\underbrace{D_1^{\star\star}(\cdot) + l_1 \frac{\partial D_1(\cdot)}{\partial l_1}}_{\substack{\text{Margin + Volume} \\ \text{effect}}} + \underbrace{l_1 \frac{\partial D_1(\cdot)}{\partial N_1^e} \frac{\partial N_1^\star(\cdot)}{\partial l_1}}_{\substack{\text{Developer participation} \\ \text{effect } (-)}}$$

$$+ \underbrace{\int_0^{\overline{x}^{\star\star}} \left[\underbrace{\frac{\partial p_1(x)}{\partial D_1^e}}_{(+)} \underbrace{\frac{\partial D_1^{\star\star}(\cdot)}{\partial l_1}}_{(-)} + \underbrace{\frac{\partial p_1(x)}{\partial D_2^e}}_{(-)} \underbrace{\frac{\partial D_2^{\star\star}(\cdot)}{\partial l_1}}_{(+)} \right]}_{\text{Personalized price effect } (-)} dx = 0. \tag{16}$$

The terms in the first line of the above first-order expression mirror those in the uniform pricing case. The term in the second line introduces a novel effect, elucidating how public developer participation fees influence the (private) personalized prices charged to consumers. To elaborate, consider that the personalized price for each consumer type x is established to extract the entire *consumer arbitrage value* from purchasing at firm i, given that the rival firm $-i$ sets a zero price. This arbitrage value is contingent upon the difference in expected interaction value. A unit increase in developer participation fee l_i detrimentally impacts this expected interaction value, consequently influencing the private personalized price. This new effect adversely affects the first-order condition, prompting each firm to unilaterally set lower developer participation prices. It's crucial to note that the incentive to establish lower developer fees due to network effects emerges here as well, albeit through a distinct mechanism than in the uniform pricing case.

Similarly, we can obtain the first-order condition with respect to l_2 for firm 2. Solving the system of fist-order conditions presented in equation (16) yields the equilibrium fees as follows.

$$l_1^P = l_2^P = \frac{t(\phi - \theta) - \theta\phi^2}{4t - 3\theta\phi}. \tag{17}$$

Substituting these equilibrium fees into the personalized pricing schedules yields

$$p_1^P(x) = \begin{cases} t(1-2x) & \text{if } x \le 1/2, \\ 0 & \text{if } x > 1/2, \end{cases} \quad p_2^P(x) = \begin{cases} 0 & \text{if } x \le 1/2, \\ t(2x-1), & \text{if } x > 1/2. \end{cases} \tag{18}$$

The price schedules, $p_i^P(x)$, in (18) are identical to those in Thisse and Vives (1988).

Substituting the equilibrium fees as in equations (17) and (18) yields the following outcome:

Lemma 2. *The equilibrium profits, the equilibrium numbers of consumers and developers, the equilibrium consumer surplus, and the equilibrium surplus of developers are:*

$$\begin{aligned}
\Pi_i^P &= \frac{t}{4} - \frac{\{(\theta-\phi)t+\theta\phi^2\}\{2(\theta+\phi)t-\theta\phi^2\}}{2(4t-3\theta\phi)^2}, \quad N_i^P = \frac{1}{2}, \quad D_i^P = \frac{2(\theta+\phi)t-\theta\phi^2}{2(4t-3\theta\phi)}, \\
CS^P &= \int_0^{\bar{x}^P} (w+\theta D_1^P - tx - p_1^P(x))dx + \int_{\bar{x}^P}^1 (w+\theta D_2^P - t(1-x) - p_2^P(x))dx \\
&= w - \frac{12t^2 - \theta(4\theta+13\phi)t + 2\theta^2\phi^2}{4(4t-3\theta\phi)}, \\
PS^P &= \int_0^{D_1^P} (\phi N_1^P - k - l_1^P)dk + \int_0^{D_2^P} (\phi N_2^P - k - l_2^P)dk = \frac{(2(\theta+\phi)t-\theta\phi^2)^2}{4(4t-3\theta\phi)^2}.
\end{aligned}$$

Although the profits are decreasing in the value of network interactions, CS^P and PS^P are increasing in θ and ϕ.

4.3 Welfare effects of pricing regimes

We compare firm prices, profits, consumer surplus, developer surplus, and the total surplus across the two regimes.

Before proceeding to compare prices in the two regimes, it is essential to establish a statistic facilitating the comparison. Given that prices in personalized pricing form a menu contingent on consumers' location, as discussed in Thisse and Vives (1988), we opt for the average price faced by consumers in personalized pricing as the key statistic for comparison. The average price in personalized pricing is defined as:

$$\mathbb{E}p^P = \int_0^{N_1^P} p_1^P(x)dx + \int_{N_1^P}^1 p_2^P(x)dx = \frac{t}{2}.$$

Proposition 1. *The average consumer price in personalized pricing is higher than the price in uniform pricing when $\phi \geq \widehat{\phi} := (\sqrt{8t+9\theta^2} - 3\theta)/2$. Developer fees are unambiguously lower in personalized pricing than in uniform pricing — i.e., $l_i^P < l_i^U$.*

The first statement of the proposition confirms the findings elucidated in Liu and Serfes (2013, Section 3.3). The subsequent portion of the proposition then delves into a comparative analysis outlined in Kodera (2015, Section 3), despite his lack of explicit discussion on the relationship.

Consistent with Thisse and Vives (1988), our findings reveal that when the developer interaction value is low, the average consumer price in personalized pricing, $t/2$, is lower than that in uniform pricing (see p_i^U in (8)). Interestingly, in contrast to Thisse and Vives (1988), we observe that consumer prices in personalized pricing can surpass those in uniform pricing when the degree of network interactions enjoyed by developers, denoted as ϕ, is substantial. This distinctive result emerges solely due to the presence of cross-sided network interactions, which are absent in Thisse and Vives (1988).

These results demonstrate how the opposing competition-enhancing effects of personalized pricing interact with the competition-dampening effects arising from consumer prices being private under personalized pricing. When the developers' network interaction value is low, cross-sided network effects do not significantly impact the outcome, leading to the traditional result that personalized pricing enhances competition, thereby lowering consumer prices. Conversely, when the developers' value from network interactions is sufficiently high, the consumer price in uniform pricing decreases. This is attributed to the ability of uniform pricing to attract more developers, who are then charged a higher price. Specifically, in uniform pricing, consumer prices decrease with an increase in ϕ as each firm unilaterally deems it profitable to expand cross-market network values for developers. As firms engage in competition and consumer prices exhibit strategic complements, this strategic effect contributes to a further reduction in uniform prices. In contrast, the menu of consumer prices in personalized pricing remains independent of the network interaction values for developers, denoted as ϕ (see $p_i(x)$ in 10 and 11), and therefore remains unchanged with variations in ϕ. Consequently, when ϕ is sufficiently high, the consumer prices in uniform pricing become lower than the average price in personalized pricing.

The fees in personalized pricing, denoted as l_i^P, are unequivocally lower than those in uniform pricing, represented as l_i^U. This distinction arises from the fact that firms are unable to leverage consumer prices to influence the mass of developers; they can only use fees charged to developers for this purpose. Consequently, firms strategically set low fees to attract developers, a strategy that proves beneficial for establishing high personalized consumer prices (refer to (13) and (14)).

Next, we aim to understand the effects of personalized pricing on the developer surplus, DS, and the total surplus, TS. In pricing regime $k \in \{U,\ P\}$, we define the total surplus as the sum of firm profits, developer surplus, and consumer surplus.

$$TS^k = \sum_{i=1}^{2} \Pi_i^k + CS^k + PS^k \text{ for } k \in \{U,\ P\}.$$

Under Assumptions 1, we obtain the following outcomes, which are summarized as in Proposition 2:

$$\Delta PS = PS^P - PS^U = \frac{\theta\phi(3\theta+\phi)(8(\theta+\phi)t - \theta\phi(3\theta+5\phi))}{16(4t-3\theta\phi)^2} > 0, \tag{19}$$

$$\Delta TS = TS^P - TS^U = \frac{\theta\phi(3\theta+\phi)(8(\theta+\phi)t - \theta\phi(9\theta+7\phi))}{16(4t-3\theta\phi)^2} > 0. \tag{20}$$

Proposition 2. *Personalized pricing improves the surplus of developers and the total surplus.*

As personalized pricing prompts firms to lower access fees l_i, the developers' surplus under personalized pricing surpasses that under uniform pricing. Additionally, these reduced fees for developers contribute to the expansion of network benefits for consumers in personalized pricing. This expansion results in a higher total surplus under personalized pricing compared to uniform pricing. The welfare implications of personalized pricing differ from those in Liu and Serfes (2013) and Kodera (2015) due to the inelastic demands on both sides, as seen in the standard Hotelling model.

Here, we examine the effects of personalized pricing on profits and consumer surplus. To do so, we define the difference in profits and consumer surplus between the two regimes as $\Delta\Pi = \Pi_i^P - \Pi_i^U$ and $\Delta CS = CS^P - CS^U$. Figure 2 illustrates the regions in which personalized pricing enhances profits or consumer surplus.

Proposition 3. *The following relationship holds.*

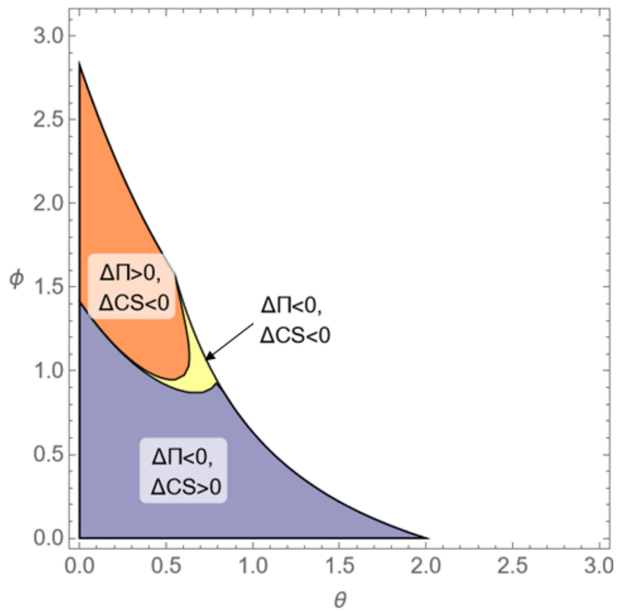

Figure 1: Comparison of profits and consumer surplus ($t = 1$ and $v = 3/2$).

- *When* $0 < \phi < \phi_1$*, consumer surplus (firm profit) under personalized pricing is higher (lower) higher than under uniform pricing — i.e.,* $\Delta CS > 0$ *and* $\Delta\Pi < 0$*.*

- *When* $\phi_1 < \phi < \phi_2$*, consumer surplus and firm profits under personalized pricing are lower than under uniform pricing — i.e.,* $\Delta CS < 0$ *and* $\Delta\Pi < 0$*.*

- *When* $\phi_2 < \phi$*, consumer surplus (firm profit) under personalized pricing is lower (higher) than under uniform pricing — i.e.,* $\Delta CS < 0$ *and* $\Delta\Pi > 0$*.*

When the developer interaction value is sufficiently low, the firm faces challenges in attracting an adequate number of content developers, even with lowered fees under personalized prices. Additionally, under this parameter configuration, the dominance of the competition-enhancing effect of personalized pricing results in lower consumer prices compared to uniform prices. A direct consequence of both consumer prices and developer fees being lower is a decrease in firm profits under personalized prices. Consequently, the personalized pricing regime, despite increasing the mass of participating developers, adversely impacts firms when $\phi < \phi_1$.

When the developer interaction value is intermediate, both firms and consumers experience adverse effects. Firm profits decline as they reduce fees to developers but struggle to establish sufficiently high consumer prices due to the intensified competition effect, resulting in lower profits. Consumers also face a disadvantage as the benefits from increased interaction with developers under personalized prices are overshadowed by the (relatively) higher average prices charged to them. In this region, only developers benefit under personalized pricing.

When the developer interaction value is high, firms experience an improvement. However, consumers fare worse under personalized pricing, where the competition-reducing effect dominates the competition-increasing effect. This is evident from the discussion following equation (18), where the average consumer price increases when ϕ is sufficiently high. Consequently, firm profits increase under personalized pricing, although consumer surplus declines.

Our results demonstrate both similarities and differences when compared to the findings presented by Liu and Serfes (2013). In particular, Liu and Serfes (2013) assert that personalized pricing is advantageous for platforms if and only if the sum of the degree of cross-market externality on consumers and participating firms exceeds a threshold value. While this conclusion implies that the effect of the degree of cross-market externality on consumers is equivalent to that on participating firms, our result, though partially resembling theirs, emphasizes that the degree of cross-market externality on developers is more critical than that on consumers in our model.

4.4 Asymmetric firms

We extend the model by considering quality asymmetry between the firms. We modify the utility when a consumer purchases from firm 1 as follows (see (1)): $U_1(p_1, D_1^e, x) = w + h + \theta D_1^e - p_1 - tx$, where $h(> 0)$ is the quality advantage of firm 1.

We discuss the effect of firm asymmetry on the consumer surplus and the total surplus. A simple calculation leads to the following proposition:

Proposition 4. *ΔCS is always decreasing in h. ΔTS is increasing in h if and only if*

$\phi < \phi_3$, where ϕ_3 is an upper bound of ϕ. Also, $\phi_3 > \phi_2$, where ϕ_2 is in Proposition 3.

First, ΔCS is decreasing in h because the dominant firm attracts many consumers and exploits their surpluses through personalized pricing. We can check the surplus extraction through personalized pricing by comparing the prices under uniform and personalized pricing. The (average) prices of firm 1 under uniform and personalized pricing, and the difference between them are

$$\begin{aligned}
p_1 &= t - \frac{\phi(3\theta+\phi)}{4} + \frac{4t - \phi(3\theta+\phi)}{2(6t - \theta^2 - 4\theta\phi - \phi^2)}h, \\
E[p_1(x)] &= \underbrace{\frac{t}{2}}_{E[t(1-2x)]} + \frac{t(4t - 3\theta\phi)}{4t^2 - \theta(2\theta+5\phi)t + \theta^2\phi^2}h, \\
E[p_1(x)] - p_1 &= \frac{\phi(3\theta+\phi)}{4} - \frac{t}{2} + \frac{4t^2(8t - \phi(9\theta+\phi)) + \theta\phi^2(3\theta+\phi)(t+\theta\phi)}{2(6t - \theta^2 - 4\theta\phi - \phi^2)(4t^2 - \theta(2\theta+5\phi)t + \theta^2\phi^2)}h
\end{aligned}$$

The coefficient of h in $E[p_1(x)] - p_1$ is positive and increasing in θ and ϕ, implying that the per-consumer payment under personalized pricing becomes higher than that under uniform pricing as the advantage of firm 1 strengthens and the cross-market externalities increase. The positive relationship between $E[p_1(x)] - p_1$ and h indicates that personalized pricing becomes more exploitative as the advantage of firm 1 strengthens.

We conclude that if a dominant firm exists in a two-sided market, we should be cautious about personalized pricing, as it is more likely to harm consumer welfare.

Second, we briefly discuss the effect of firm asymmetry on the total surplus. The efficiency of personalized pricing in allocating consumers to the firms. The firm with superior quality, including network benefits, consistently prevails along the Hotelling line, akin to standard Bertrand competition. This result suggests that the more efficient firm at each specific point concerning welfare provides consumers with superior offerings. Consequently, the resulting allocation is invariably efficient under personalized pricing. It is crucial to note that there is no correlation between any two points, a pivotal aspect in comprehending competition at each point.

However, this mechanism does not apply under uniform pricing, except in symmetric cases. The complexity arises as each firm must weigh the gains from inframarginal consumers when determining its uniform price. In terms of overall welfare, the more efficient firm may hesitate to attract more consumers by lowering its price, as this reduction would extend to its inframarginal consumers.

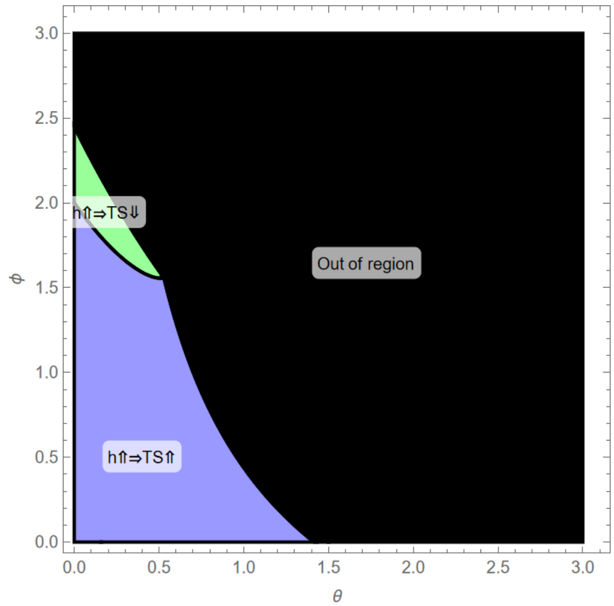

Figure 2: The impact of a marginal increase in h on the total surplus ($t = 1$).

5 Policy Implications

In this section, we delve into the policy implications arising from our research. Personalized pricing, particularly the prohibition of first-degree price discrimination, has been proposed as a policy tool to mitigate scenarios where the rent *appropriation effect* outweighs the *demand expansion effect* (Bourreau and De Streel (2018)). In the following, we outline some policy implications derived from our work.

Policy Implication 1. *Under competition in two-sided markets, personalized prices on the consumers' side benefit developers. Thus, any regulation that bans personalized prices to consumers hurts developers.*

In our study, we uncover intriguing effects of altering the nature of pricing on the consumers' side on the developers' (complementors') side. Specifically, the ability to set personalized prices for consumers creates an incentive for the platform to increase consumer surplus by expanding participation on the developers' side. In simpler terms, the platform's capacity to (unilaterally) extract surplus from consumers more effectively under personalized pricing serves as motivation to boost developer participation. This dynamic, where price discrimination on one side influences the participation of the other side, is reminiscent of the findings in de Cornière et al. (2023). Increased competition for consumers prompts the rival platform to respond by lowering developer fees, ultimately benefiting developers in equilibrium. Policymakers, when contemplating the prohibition of personalized prices on the consumers' side, must also consider the potential (negative) impact of such a regulation on the developers' side.

Policy Implication 2. *Greater transparency on personalized pricing to complementors may be a more effective tool than an outright ban on personalized pricing.*

In recent policy reports, there have been discussions regarding the mandate of greater transparency for consumers regarding the algorithms employed by firms for personalized pricing (See Rott et al. (2022) and Bourreau and De Streel (2018)). The focus of these regulations is to maintain consumer trust in the market and avoid market failures. While the above Policy Implication 1 advocates for transparency, the transparency of consumer prices is directed toward the developers' side and is nuanced. Specifically, the above policy implication suggests that personalized pricing algorithms should be made more transparent to developers (complementors). Under personalized pricing, developers (complementors) do not observe consumer prices and, therefore, cannot base their expectations on them (in contrast to the uniform pricing case). This absence of information makes consumer prices less sensitive to the network value of developers. The competition-dampening effect of a lack of information can be avoided by informing developers about the algorithm employed to implement personalized prices. Thus, this policy retains the competitive benefits of personalized pricing without imposing any restrictions on firm strategies.

6 Conclusions

We revisited the issue of personalized pricing under competition and its impact on welfare in markets featuring network effects. Contrary to the established result that consumers benefit when competing firms employ personalized prices, we uncovered a counterintuitive outcome when the developers' network interaction value is sufficiently high. This intriguing result, driven solely by network effects, provides a rationale for why firms like Uber, among others, find it profitable to implement personalized pricing in platform markets. Specifically, in the presence of network effects, publicly observed prices serve as a tool to shape favorable expectations regarding network interaction value at the firm. Consequently, as the value of network interactions increases, firms fiercely compete to attract consumers. The implementation of personalized pricing, which makes consumer prices private, dampens this competitive channel due to the presence of network effects. As a result, we find that when the value of network interactions is low, we align with the traditional result that personalized prices increase competition for consumers and hurt the competing firms. However, when the value of network interactions is high, the competition-dampening effect of personalized prices dominates, making competing firms better off. These results enable us to derive valuable policy implications.

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Appendix

Proof of Lemma 1. Solving simultaneously the system first order conditions in equations (6) and (7) yields the symmetric equilibrium fees as

$$p_i^U = t - \frac{\phi(3\theta + \phi)}{4}, \quad l_i^U = \frac{\phi - \theta}{4} \text{ for } i = 1, 2.$$

Substituting these prices into the profit expression yields the expressions presented in Lemma 1. ■

Proof of Lemma 2. Solving simultaneously the system first order conditions in equations (16) yields the symmetric equilibrium fees as

$$l_1^P = l_2^P = \frac{t(\phi - \theta) - \theta\phi^2}{4t - 3\theta\phi}.$$

Substitute the developer fees into personalized consumer prices and obtain

$$p_1^P(x) = \begin{cases} t(1-2x) & \text{if } x \leq 1/2, \\ 0 & \text{if } x > 1/2, \end{cases} \quad p_2^P(x) = \begin{cases} 0 & \text{if } x \leq 1/2, \\ t(2x-1), & \text{if } x > 1/2, \end{cases}$$

Substituting these prices into the profit expression yields the expressions presented in Lemma 2. ■

Proof of Proposition 1. The average consumer price under personalized pricing is given as

$$\mathbb{E}p^P = \int_0^{N_1^P} p_1^P(x)dx + \int_{N_1^P}^1 p_2^P(x)dx = \frac{t}{2}.$$

Comparing the above-average (personalized) price with the consumer price in the uniform pricing case yields

$$\mathbb{E}p^P - p^U = \frac{\phi(3\theta+\phi)}{4} - \frac{t}{2}.$$

The above expression is positive when $\phi > \widehat{\phi} = (\sqrt{8t+9\theta^2} - 3\theta)/2$.

Next comparing the developer fees in the two regimes yields

$$l_i^P - l_i^U = -\frac{\theta\phi(3\theta+\phi)}{4(4t-3\theta\phi)} < 0.$$

The above inequality always holds under Assumption 1.

■

Proof of Proposition 2. The proof is straightforward by just reviewing the equation (19) and (20). ■

Proof of Proposition 3. Comparing the consumer surplus under personalized pricing with the consumer surplus under uniform pricing yields

$$\Delta CS = CS^P - CS^U = \frac{8t^2 + \theta\phi(3\theta+\phi)(\theta+3\phi) - 2t\phi(9\theta+2\phi)}{4(4t-3\theta\phi)}.$$

The sign of the above expression depends on the numerator, which we define as $\Lambda := 8t^2 + \theta\phi(3\theta+\phi)(\theta+3\phi) - 2t\phi(9\theta+2\phi)$.

Equating Λ and solving with 0 and solving with respect to ϕ yields

$$\phi_1 = \frac{\left(4t + \epsilon^{1/3} - 10\theta^2 + \frac{16t^2+73\theta^4+82\theta^2 t}{\epsilon^{1/3}}\right)}{9\theta}.$$

where $\epsilon = -595\theta^6 + 64t^3 - 480\theta^2t^2 - 1392\theta^4 t$
$+ 9\sqrt{6}\sqrt{-72\theta^{12} - 256\theta^2t^5 - 672\theta^4t^4 + 276\theta^6t^3 + 1606\theta^8t^2 + 711\theta^{10}t}$.

Comparing the profit under personalized pricing with the profit under uniform pricing yields

$$\Delta\Pi = \Pi_i^P - \Pi_i^U = \frac{32t^2\theta(6\theta+\phi)+\theta^2\phi^2(3\theta+\phi)(3\theta+17\phi)-4t\theta\phi(6\theta^2+12\phi^2+47\theta\phi)-64t^3}{16(4t-3\theta\phi)^2}.$$

The sign of the above expression depends on the numerator which we define as $\Gamma := 32t^2\theta(6\theta+\phi)+\theta^2\phi^2(3\theta+\phi)(3\theta+17\phi)-4t\theta\phi(6\theta^2+12\phi^2+47\theta\phi)-64t^3$.

Equating Γ and solving with 0 and solving with respect to ϕ yields ϕ_2. We suppress the expression for ϕ_2 for brevity. It is available upon request. Simulate the relevant parameter range and comparing ϕ_1 and ϕ_2, we note that $\phi_1 < \phi_2$. ■

Proof of Proposition 4. In the asymmetric case, the utility when a consumer purchases from firm 1 is $U_1(p_1, D_1^e, x) = w + h + \theta D_1^e - p_1 - tx$ $(h > 0)$. First, we derive the equilibrium under uniform pricing. Following the same method in the basic model, the mass of consumers and developers are

$$\begin{aligned}
D_1^\star(p_1,p_2,l_1,l_2) &= \frac{1}{2} - \frac{(p_1-p_2)+\theta(l_1-l_2)-h}{2(t-\theta\phi)},\\
D_2^\star(p_1,p_2,l_1,l_2) &= \frac{1}{2} - \frac{(p_2-p_1)+\theta(l_2-l_1)+h}{2(t-\theta\phi)},\\
N_1^\star(l_1,l_2,p_1,p_2) &= \frac{\phi(\theta(l_1+l_2)-p_1+p_2+t+h)-\theta\phi^2-2l_1t}{2(t-\theta\phi)},\\
N_2^\star(l_1,l_2,p_1,p_2) &= \frac{\phi(\theta(l_1+l_2)+p_1-p_2+t-h)-\theta\phi^2-2l_2t}{2(t-\theta\phi)}.
\end{aligned}$$

The profit functions of firms are

$$\begin{aligned}
\Pi_1^\star(p_1,p_2,l_1,l_2) &= p_1D_1^\star(\cdot)+l_1N_1^\star(\cdot)\\
&= \tfrac{h(l_1\phi+p_1)+p_1(-\theta\phi-\theta l_1-l_1\phi+\theta l_2+p_2+t)+l_1(l_1(\theta\phi-2t)+\phi(-\theta\phi+\theta l_2+p_2+t))-p_1^2}{2(t-\theta\phi)},\\
\Pi_2^\star(p_1,p_2,l_1,l_2) &= p_2D_2^\star(\cdot)+l_2N_2^\star(\cdot)\\
&= \tfrac{l_2\left(\phi(-h+\theta(l_1+l_2)+p_2-p_1-t)-\theta\phi^2-2l_2t\right)-p_2(\theta\phi+h-\theta l_1+\theta l_2-p_1+p_2-t)}{2(t-\theta\phi)}.
\end{aligned}$$

Checking the first-order condition, we derive the equilibrium fees.

$$\begin{aligned}
p_1^U &= t - \frac{\phi(3\theta+\phi)}{4} + \frac{(4t-\phi(3\theta+\phi))h}{2\left(6t-\theta^2-4\theta\phi-\phi^2\right)},\\
p_2^U &= t - \frac{\phi(3\theta+\phi)}{4} - \frac{(4t-\phi(3\theta+\phi))h}{2\left(6t-\theta^2-4\theta\phi-\phi^2\right)},\\
l_1^U &= \frac{1}{4}\left(\phi-\theta+\frac{2(\phi-\theta)h}{6t-\theta^2-4\theta\phi-\phi^2}\right),\ l_2^U = \frac{1}{4}\left(\phi-\theta-\frac{2(\phi-\theta)h}{6t-\theta^2-4\theta\phi-\phi^2}\right).
\end{aligned}$$

The second-order condition requires that $t > \frac{1}{8}\left(\theta^2 + 6\theta\phi + \phi^2\right)$. The profit of each firm is

$$\Pi_1^U = \frac{\left(8t - \left(\theta^2 + 6\theta\phi + \phi^2\right)\right)\left(6t - \left(\theta^2 + 4\theta\phi + \phi^2\right) + 2h\right)^2}{16\left(6t - \left(\theta^2 + 4\theta\phi + \phi^2\right)\right)^2},$$
$$\Pi_2^U = \frac{\left(8t - \left(\theta^2 + 6\theta\phi + \phi^2\right)\right)\left(6t - \left(\theta^2 + 4\theta\phi + \phi^2\right) - 2h\right)^2}{16\left(6t - \left(\theta^2 + 4\theta\phi + \phi^2\right)\right)^2}.$$

Consumer, developer, and total surplus are

$$CS^U = w - \frac{5t}{4} + \frac{1}{4}\left(\left(\theta^2 + 4\theta\phi + \phi^2\right) + 2h + \frac{4th^2}{\left(6t - \theta^2 - 4\theta\phi - \phi^2\right)^2}\right),$$
$$PS^U = \frac{1}{16}(\theta + \phi)^2\left(1 + \frac{4h^2}{\left(6t - \theta^2 - 4\theta\phi - \phi^2\right)^2}\right),$$
$$TS^U = w - \frac{t}{4} + \frac{1}{16}\left(3(\theta + \phi)^2 + 8h + \frac{\left(80t - 4\left(\theta^2 + 10\theta\phi + \phi^2\right)\right)h^2}{\left(6t - \theta^2 - 4\theta\phi - \phi^2\right)^2}\right).$$

Then, we derive the equilibrium under personalized pricing. In this case, the personalized consumer fee of each firm is:

$$p_1(x) = \begin{cases} h + \theta(N_1^e - N_2^e) + t(1 - 2x) & \text{if } x \le \bar{x}, \\ 0 & \text{if } x > \bar{x}, \end{cases}$$
$$p_2(x) = \begin{cases} 0 & \text{if } x \le \bar{x}, \\ -h + \theta(N_2^e - N_1^e) + t(2x - 1), & \text{if } x > \bar{x}, \end{cases}$$

where $\bar{x} = (h + t + \theta(N_1^e - N_2^e))/(2t)$. Substituting the prices into developers' demand, we derive the mass of developers as below.

$$N_1^{\star\star}(l_1, l_2) = \frac{\phi(h + \theta(l_1 + l_2) + t) - \theta\phi^2 - 2l_1 t}{2(t - \theta\phi)},$$
$$N_2^{\star\star}(l_1, l_2) = \frac{\phi(-h + \theta(l_1 + l_2) + t) - \theta\phi^2 - 2l_2 t}{2(t - \theta\phi)}.$$

The profit functions of firms are

$$\Pi_1(l_1, l_2) = \int_0^{x^{\star\star}} p_1(x)dx + l_1 N_1^{\star\star}(\cdot)$$
$$= \frac{t(t - \theta\phi + h + \theta(l_2 - l_1))^2}{4(t - \theta\phi)^2} + \frac{(\phi(h + t - \theta\phi + \theta l_2) - (2t - \theta\phi)l_1)l_1}{2(t - \theta\phi)},$$
$$\Pi_2(l_1, l_2) = \int_{x^{\star\star}}^1 p_2(x)dx + l_2 N_2^{\star\star}(\cdot)$$

$$= \frac{t(t-\theta\phi-h+\theta(l_1-l_2))^2}{4(t-\theta\phi)^2} + \frac{(\phi(t-\theta\phi-h+\theta l_2)-(2t-\theta\phi)l_2))l_2}{2(t-\theta\phi)},$$

where $x^{\star\star} = (h+t+\theta(N_1^{\star\star}-N_2^{\star\star}))/(2t)$. Checking the first-order condition, we derive the equilibrium developer fees and $x^{\star\star}$:

$$\begin{aligned}
l_1^P &= \frac{t(\phi-\theta)-\theta\phi^2}{4t-3\theta\phi} + \frac{(t(\phi-\theta)-\theta\phi^2)h}{4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2}, \\
l_2^P &= \frac{t(\phi-\theta)-\theta\phi^2}{4t-3\theta\phi} - \frac{(t(\phi-\theta)-\theta\phi^2)h}{4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2}, \\
\bar{x}^{\star\star} &= \frac{1}{2} + \frac{(4t-3\theta\phi)h}{2(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2)}.
\end{aligned}$$

Then, we substitute the developer fees into personalized consumer fees and obtain

$$p_1^P(x) = \begin{cases} t(1-2x) + \dfrac{(4t-3\theta\phi)th}{4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2} & \text{if } x \le \bar{x}^{\star\star}, \\ 0 & \text{if } x > \bar{x}^{\star\star}, \end{cases}$$

$$p_2^P(x) = \begin{cases} 0 & \text{if } x \le \bar{x}^{\star\star}, \\ t(2x-1) - \dfrac{(4t-3\theta\phi)th}{4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2}, & \text{if } x > \bar{x}^{\star\star}. \end{cases}$$

The second-order condition requires that $t > \frac{1}{8}\theta\left(\sqrt{\theta^2+12\theta\phi+4\phi^2}+\theta+6\phi\right)$. The profit of each firm is

$$\begin{aligned}
\Pi_1^P &= \frac{(4t+\phi^2)\left(2\theta^2\phi^2+4t^2-\theta t(\theta+6\phi)\right)\left(\theta^2\phi^2+h(4t-3\theta\phi)+4t^2-\theta t(2\theta+5\phi)\right)^2}{4(4t-3\theta\phi)^2\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2}, \\
\Pi_2^P &= \frac{(4t+\phi^2)\left(2\theta^2\phi^2+4t^2-\theta t(\theta+6\phi)\right)\left(\theta^2\phi^2+h(3\theta\phi-4t)+4t^2-\theta t(2\theta+5\phi)\right)^2}{4(4t-3\theta\phi)^2\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2}.
\end{aligned}$$

Consumer, developer, and total surplus are

$$\begin{aligned}
CS^P &= w - \frac{12t^2-\theta(4\theta+13\phi)t+2\theta^2\phi^2}{4(4t-3\theta\phi)} + \frac{h}{2} - \frac{(4t-3\theta\phi)^2th^2}{4\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2}, \\
PS^P &= \frac{\left(2(\theta+\phi)t-\theta\phi^2\right)^2}{4}\left(\frac{1}{(4t-3\theta\phi)^2} + \frac{h^2}{\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2}\right), \\
TS^P &= w - \frac{16t^3-12(\theta^2+4\theta\phi+\phi^2)t^2+\theta\phi(12\theta^2+37\theta\phi+16\phi^2)t-\theta^2\phi^3(6\theta+5\phi)}{4(4t-3\theta\phi)^2} \\
&\quad + \frac{h}{2} + \frac{(16t^3-4(\theta^2+4\theta\phi-3\phi^2)t^2+\theta\phi^2(\theta^2-16\phi)t+5\theta^2\phi^4)h^2}{4\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2}.
\end{aligned}$$

Comparing the consumer surplus under personalized pricing with that under uniform pricing yields

$$\begin{aligned}\Delta CS &= CS^P - CS^U \\ &= -\frac{(3\theta+\phi)(\theta+3\phi)}{12}+\frac{7t}{18}+\frac{4t+9\theta^2}{9(4t-3\theta\phi)} \\ &\quad -\left(\frac{(4t-3\theta\phi)^2}{4\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2)\right)^2}+\frac{1}{\left(6t-\theta^2-4\theta\phi-\phi^2\right)^2}\right)th^2.\end{aligned}$$

This difference is always decreasing in h as

$$\frac{\partial \Delta CS}{\partial h}=-2\left(\frac{(4t-3\theta\phi)^2}{4\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2)\right)^2}+\frac{1}{\left(6t-\theta^2-4\theta\phi-\phi^2\right)^2}\right)t<0.$$

Comparing the total surplus under personalized pricing with that under uniform pricing yields

$$\begin{aligned}\Delta TS &= TS^P - TS^U \\ &= \frac{Hh^2}{4\left(6t-\theta^2-4\theta\phi-\phi^2\right)^2\left(4t^2-\theta(2\theta+5\phi)t+\theta^2\phi^2\right)^2} \\ &\quad +\frac{\theta\phi(3\theta+\phi)\left(8(\theta+\phi)t-\theta\phi(9\theta+7\phi)\right)}{16(4t-3\theta\phi)^2},\end{aligned}$$

where $H \equiv 256t^5-128\phi(3\theta-2\phi)t^4-8(4\theta^4+11\theta^3\phi+10\theta^2\phi^2+109\theta\phi^3+16\phi^4)t^3+\phi(12\theta^5+117\theta^4\phi+470\theta^3\phi^2+1053\theta^2\phi^3+272\theta\phi^4+12\phi^5)t^2-\theta\phi^2(3\theta^5+58\theta^4\phi+294\theta^3\phi^2+530\theta^2\phi^3+187\theta\phi^4+16\phi^5)t+\theta^2\phi^4(3\theta+\phi)(2\theta^3+16\theta^2\phi+25\theta\phi^2+5\phi^3)$. ΔTS is increasing in h if and only if $H>0$.

We denote the threshold of ϕ as ϕ_3, then ΔTS is increasing in h if and only if $\phi<\phi_3$. In Figure 3, we show that ϕ_3 is higher than ϕ_2, where ϕ_2 is the threshold of ϕ under which personalized pricing improves firms' profits in the symmetric case.

■

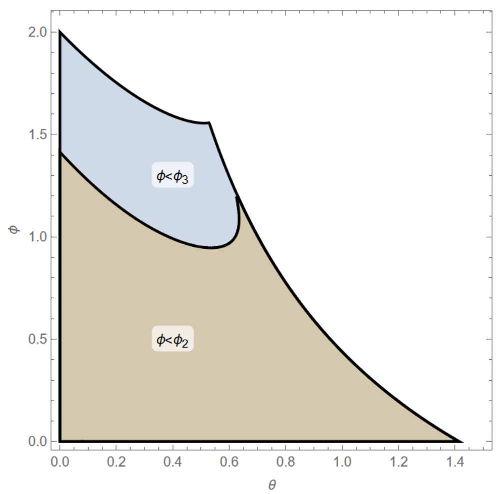

Figure 3: Comparison of ϕ_2 and ϕ_3.