WORKING **PAPER**

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"The welfare effects of group and personalized pricing in markets with multi-unit buyers with a decreasing disutility cost in consumption"

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The welfare effects of group and personalized pricing in markets with multi-unit buyers with a decreasing disutility cost in consumption[*]

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Abstract

This paper assesses the welfare effects of firms' ability to use data for group and personalized pricing in markets with unit ($q = 1$) and multi-unit demand consumers ($q > 1$). The "disutility cost" of not consuming the ideal good is a function of units purchased and can increase at a decreasing rate $\beta \in [0, 1]$ as consumption increases (β is the elasticity of the disutility cost with respect to q). Group pricing (GP) and personalized pricing (PP) are compared to uniform pricing (UP). GP always boosts profits at the expense of consumers. When $\beta = 0$, PP reduces industry profits and boosts consumer welfare. The same happens when q is low and/or β is sufficiently high. In contrast, if heterogeneity in demand is sufficiently high and β is sufficiently low, PP can enhance profits at the expense of consumer welfare.

1 Introduction

In the era of Internet of Things data collection for price personalization is virtually infinite. The formula behind personalized price offers can be explained by many variables such as consumer preferences for product attributes or brands, volume purchasing habits, location, to name a few

(OECD, 2018). The growth of hypersegmentation through price personalization in a wide range of industries has spurred active research in marketing and economics.

Since the seminal work on PP by Thisse and Vives (1988), a rich and diverse literature has emerged. Most of this literature investigates the impact of personalized pricing (PP) on profits and welfare using the standard Hotelling model with *unit* demand consumers. A common feature in these models is that PP benefits consumers at the expense of profits (Thisse and Vives, 1988, Shaffer and Zhang, 2002, Matsumura and Matsushima, 2015). However, in many markets, some consumers buy multiple units of the same good. When product differentiation is explained by intrinsic characteristics of products (e.g. dark versus white chocolate; ice cream flavors, X-burger McDonalds versus Burger King, etc.) and consumers buy multiple units, the disutility cost of not buying the ideal good may vary with the consumption level.

The aim of this paper is to assess the profit and welfare effects of group pricing (GP) and PP in a market where some consumers have unit demand while others buy multiple units: a L(ow)-type consumer purchases only one unit $q = 1$ and a H(igh)-type consumer purchases $q > 1$ units. Furthermore, the "disutility cost" per unit of distance is a function of units purchased, i.e. $t(q) = q^{\beta}$ with $\beta \in [0,1]$. β is the elasticity of disutility cost $t(q)$ with respect to consumption q. When $0 < \beta < 1$ the marginal disutility cost is decreasing, suggesting that, all else equal, as consumption increases, the incremental increase in disutility that results from the consumption of one additional unit declines.[1]

Some recent studies highlight the importance of extending the analysis of PP in the context of the Hotelling model to other demand settings and transport cost configuration. Esteves and Shuai (2022) study PP in a delivery pricing model[2] with a CES demand function.[3] They show that new

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[1] Consider the following example. Suppose Mr. Y is very hungry and has not eaten any food all day. He wants to buy 5 X-burgers. McDonald's (A) is located at 0 and Burger King (B) is located at 1. Mr. Y ideal's X-burger is located say at x. Suppose he buys 5 X-burgers from Burger King. When he finally starts to eat, he values more the fact of not eating his ideal X-burger (supporting a disutility cost equal to $(1-x)$). Should he necessarily support a disutility cost of $5(1-x)$ when buying the 5 burgers? Maybe not! As he keeps eating more and more burgers he can value less and less the fact of not eating his ideal X-burger. As his appetite decreases it comes to a point where after some level of consumption he doesn't care anymore about the burger he is eating. Perhaps his disutility cost is simply say, for instance, $\sqrt[3]{5}(1-x)$.

[2] In a delivery pricing model firms support the transport cost.

[3] Esteves and Reggiani (2014) and Zhang, et al. (2019) look at behavior-based price discrimination in a Hotelling model with a CES demand function. BBPD is always bad for profits but an increase in ε reduces the negative effects

results arise compared to a mill pricing model. If demand is sufficiently elastic, PP boosts profits at the expense of consumer surplus and overall welfare. Other studies do not allow demand to vary with prices, but relax the assumption of unit demand for all consumers. Shin and Sudhir (2010) study behavior-based price discrimination (BBPD) in a Hotelling model composed by unit and multiple units demand consumers. BBPD is bad for profits. Esteves (2022) uses a similar demand setting to investigate the profit effects of PP in a homogeneous product market where consumers have preferences for stores. The paper only looks at the profit effects of PP: PP can increase profits if demand heterogeneity is sufficiently high. The disutility cost is constant for L and H type consumers.

This note shows that the elasticity of the disutility cost with respect to consumption level (β) plays a vital role in determining the profit and welfare effects of data-based pricing. If data only allows for GP, GP always boosts profits and reduces consumer surplus. β increases profits and reduces consumer welfare. Comparing UP and PP different results can emerge. When $\beta = 0$ the disutility cost is perfectly inelastic: PP reduces industry profits and boosts consumer welfare. The same happens when q is low and/or β is sufficiently high (standard literature results). In contrast, if heterogeneity in demand is high enough and β is sufficiently low, PP enhances industry profits at the expense of consumer welfare.

2   The model

There are two firms A and B who sell competing brands of a good produced at zero marginal cost. The total number of consumers in the market is normalized to one. A consumer can either buy the good from A or B, but not from both. Firm A and B are located at the extremes of the interval $[0, 1]$. Consumers are uniformly distributed along this interval. I call the consumer located at x simply consumer x. If consumer x is at 'distance' $d^A = x$ from good A and $d^B = 1 - x$ from good B.

Each consumer receives a gross utility v from consuming a unit of the good, v is large enough so the market is covered. There are two types of consumers in the market, $j \in \{L, H\}$: a L(ow)-type purchases only one unit of the good ($q = 1$) and a H(igh)-type purchases $q > 1$ units of the good.[4] The proportion of L and H type consumers in the market is, respectively, α and $1 - \alpha$, with

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of BBPD. BBPD can be welfare enhancing if demand elasticity is sufficiently high.

[4]Shin and Sudhir (2010) and Esteves (2022) use a similar assumption to model consumer heterogeneity in terms of

$0 < \alpha < 1$. A $j - type$ consumer located at x obtains a surplus of

$$\begin{cases} Q^j(v - p_A) - t(Q^j)x & \text{if buys good A} \\ Q^j(v - p_B) - t(Q^j)(1 - x) & \text{if buys good B} \end{cases}, \tag{1}$$

with $Q^H = q$, $Q^L = 1$, and

$$t(Q^j) = \begin{cases} 1 & when & Q^L = 1 \\ q^\beta & when & Q^H = q \end{cases} \quad \text{with } \beta \in [0, 1]. \tag{2}$$

When product differentiation is explained by intrinsic characteristics of products the disutility cost may vary with consumption level. Suppose the "disutility cost" per unit of distance is a function of units purchased, i.e. $t(q) = q^\beta$ with $\beta \in [0, 1]$. The impact of an increase in q on $t(q)$ is smaller the lower is β. β is the elasticity of disutility cost $t(q)$ with respect to consumption q. When $\beta = 0$ the disutility cost is perfectly inelastic suggesting that an increase in consumption has no effect on the disutility cost $t(q)$.[5] When $\beta = 1$ the disutility cost is linear in consumption and the disutility cost changes at the same rate as q. When $0 < \beta < 1$ the marginal disutility is decreasing suggesting that, all else equal, as consumption increases, the incremental increase in disutility that results from the consumption of one additional unit declines.

Three pricing policies are considered. Under uniform pricing, firm $i = A, B$ charges the same price to all consumers, p_i^{UP}. Under GP firms segment consumers in two groups (H and L), and price accordingly: p_i^H and p_i^L, $i = A, B$. Under PP firms have data about demand types and the location of each consumer x: Each firm quotes $p_i^j(x)$ to each consumer located at x; $j \in \{L, H\}$.

3   Benchmark: Uniform pricing

To isolate the effect GP and PP on profits and welfare, consider first the benchmark where each firm charges one price to all consumers. A $j - type$ consumer is indifferent between buying from the A and B if she/he is located at $\widehat{x}^j$:

$$Q^j(v - p_A^{UP}) - t(Q^j)\widehat{x}^j = Q^j(v - p_B^{UP}) - t(Q^j)(1 - \widehat{x}^j).$$

Thus,

$$\widehat{x}^L = \frac{1}{2} + \frac{p_B^{UP} - p_A^{UP}}{2}. \tag{3}$$

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demand.

[5]In this case L and H type consumers support the same disutility cost. This is the case in Esteves (2022).

$$\widehat{x}^H = \frac{1}{2} + \frac{q^{1-\beta}\left(p_B^{UP} - p_A^{UP}\right)}{2}. \qquad (4)$$

Considering firm A's demand:

$$D_A^{UP}(p_A^{UP}, p_B^{UP}) = \alpha\left(\frac{1}{2} + \frac{p_B^{UP} - p_A^{UP}}{2}\right) + (1-\alpha)q\left(\frac{1}{2} + \frac{q^{1-\beta}\left(p_B^{UP} - p_A^{UP}\right)}{2}\right)$$

Profits are:

$$\pi_A^{UP}(p_A^{UP}, p_B^{UP}) = p_A^{UP}D_A^{UP}(p_A^{UP}, p_B^{UP}) \qquad (5)$$

$$\pi_B^{UP}(p_A^{UP}, p_B^{UP}) = p_B^{UP}\left[1 - D_A^{UP}(p_A^{UP}, p_B^{UP})\right]. \qquad (6)$$

Proposition 1: *Under UP in the symmetric NE:*

(i) each firm charges

$$p^{UP} = q^\beta \frac{\alpha + q(1-\alpha)}{q^2(1-\alpha) + q^\beta \alpha} \qquad (7)$$

(ii) each firm's profit is

$$\pi^{UP} = \frac{1}{2}\frac{q^\beta\left(\alpha + q(1-\alpha)\right)^2}{q^\beta \alpha + q^2(1-\alpha)} \qquad (8)$$

(iii) welfare and consumer surplus are, respectively:

$$W^{UP} = v\left[\alpha + q(1-\alpha)\right] - \frac{1}{4}\left[\alpha + (1-\alpha)q^\beta\right],$$

$$CS^{UP} = v\left[\alpha + q(1-\alpha)\right] - \frac{1}{4}\left[\alpha + (1-\alpha)q^\beta\right] - \frac{q^\beta\left(\alpha + q(1-\alpha)\right)^2}{q^\beta \alpha + q^2(1-\alpha)}.$$

As expected, in a unit demand model ($\alpha = 1$), Proposition 1 converges to the standard Hotelling results. Consider now the extreme case in which all consumers demand $q > 1$ units ($\alpha = 0$), and $p^{UP} = q^{\beta-1}$. Demand is more price elastic the higher is q. An increase in p reduces more the utility of each H-type consumer than that of each L-type consumer. The higher utility reduction implies that High demand consumers are more price elastic than Low demand consumers. Hence an increase in q raises the price elasticity of demand, intensifies price competition and reduces the equilibrium uniform price.[6] It is also interesting to look at the effect of β: $\frac{\partial p^u}{\partial \beta} > 0$, suggesting that an increase in β relaxes price competition and increases p^{UP}. When $\beta = 0$ the disutility cost is perfectly inelastic (an increase in q has no effect on $t(q)$). This is equivalent to the case where consumers only value the

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[6]Similarly, a reduction in α makes the demand more elastic too.

disutility associated to the first unit consumed. When $0 < \beta < 1$ the disutility cost increases with q at a decreasing rate, p^{UP} increases with β. When $\beta = 1$ the disutility cost is linear in consumption and the disutility cost changes at the same rate as q. p^{UP} converges to the standard Hotelling results.[7]

Summing up, under UP firms compete more aggressively in prices in markets where the heterogeneity of demand is high and β is low.[8]

4 Group pricing

Under group pricing firms segment consumers in two groups (H and L), so each firm sets a price to a H and a L type consumer: p_i^H and p_i^L, $i = A, B$. Using equations (3) and (4), considering firm A:

$$\pi_A^L = \alpha p_A^L \left(\frac{1}{2} + \frac{p_B^L - p_A^L}{2} \right) \text{ and } \pi_A^H = (1 - \alpha) q p_A^H \left(\frac{1}{2} + \frac{q \left(p_B^H - p_A^H \right)}{2 q^\beta} \right). \tag{9}$$

Proposition 2. *Under group pricing:*

(i) firm i price offers are:

$$p_i^L = 1 \text{ and } p_i^H = q^{\beta - 1}. \tag{10}$$

(ii) Profits are

$$\pi^{GP} = \frac{1}{2} \left(\alpha + q^\beta (1 - \alpha) \right). \tag{11}$$

(iii) Welfare and Consumer surplus are:

$$W^{GP} = v \left[\alpha + q(1 - \alpha) \right] - \frac{1}{4} \left[\alpha + (1 - \alpha) q^\beta \right] \tag{12}$$

$$CS^{GP} = v \left[\alpha + q(1 - \alpha) \right] - \frac{5}{4} \left[\alpha + (1 - \alpha) q^\beta \right]. \tag{13}$$

In this situation, there is *best-response symmetry* (Corts, 1998): both firms are unanimous with regard to the price targeted to low and high type consumers. The comparison between UP and GP is clear: with GP firms price high to unit demand consumers and price low to the H-type consumers, exactly as one would expect. In contrast to competition under UP, an increase in q is good for profits. The impact of β is similar under both price policies. Firms charge higher prices as β increases.

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[7]When $0 < \alpha < 1$, it is straightforward to show that $\frac{\partial \pi^{UP}}{\partial \beta} = \frac{\partial \pi^u}{\partial \beta} = \frac{1}{2} (\ln q) q^\beta q^2 (1 - \alpha) \frac{(-q - \alpha + q\alpha)^2}{\left(q^2 \alpha - q^\beta \alpha - q^2 \right)^2} > 0$

[8]For this reason, we will see that PP can increase profits as long as q is high and β is low.

5   Personalized Pricing

Assume now that firms' data discloses full information about consumers' preferences and demand types. Hence, for consumer x each firm quotes $p_i^j(x)$, with $j = L, H$. Consider, for instance, a H demand consumer located at $x \leq \frac{1}{2}$. Given $p_A^L(x)$ and $p_B^L(x)$, consumer x is indifferent between buying good A or B as long as $qp_A^L(x) + q^\beta x = qp_B^L(x) + q^\beta(1-x)$. The best price firm B can offer to this consumer is $p_B^L(x) = 0$. In order not to lose this consumer, firm A needs to quote $p_A^L(x) = \frac{q^\beta(1-2x)}{q}$. Similarly for a consumer located at $x > \frac{1}{2}$. Doing the same for a unit demand consumer, we obtain the following proposition.

Proposition 3. *Under perfect personalized pricing:*

(i) firm A and B price schedules are:

$$p_A^L(x) = \begin{cases} 1 - 2x & for \quad x \leq \frac{1}{2} \\ 0 & for \quad x > \frac{1}{2} \end{cases} \quad and \quad p_A^H(x) = \begin{cases} \frac{q^\beta(1-2x)}{q} & for \quad x \leq \frac{1}{2} \\ 0 & for \quad x > \frac{1}{2} \end{cases}, \tag{14}$$

$$p_B^L(x) = \begin{cases} 2x - 1 & for \quad x \geq \frac{1}{2} \\ 0 & for \quad x < \frac{1}{2} \end{cases} \quad and \quad p_B^H(x) = \begin{cases} \frac{q^\beta(2x-1)}{q} & for \quad x \geq \frac{1}{2} \\ 0 & for \quad x < \frac{1}{2} \end{cases}. \tag{15}$$

(ii) Equilibrium profits are

$$\pi^{PP} = \frac{1}{4}\left[\alpha + q^\beta(1-\alpha)\right]. \tag{16}$$

(iii) Welfare and Consumer surplus are:

$$W^{PP} = v\left[\alpha + q(1-\alpha)\right] - \frac{1}{4}\left[\alpha + (1-\alpha)q^\beta\right] \tag{17}$$

$$CS^{PP} = v\left[\alpha + q(1-\alpha)\right] - \frac{3}{4}\left[\alpha + (1-\alpha)q^\beta\right]. \tag{18}$$

6   Discussion and final remarks

Because all consumers buy from the closest firm in the three price regimes, the pricing policy has no effect on social welfare. With GP, H-type consumers are better off, while L-type consumers are worse off. However, compared to UP, because welfare remains the same under GP and profits increase, it must be the case that consumers are worse off under GP. This is true for all α, q and β.

Proposition 4. *Comparing UP with PP:*

1. *When $\beta = 1$: profits fall and consumer surplus increases with PP.*

2. *When $0 \leq \beta < 1$:*

i. *For all α, PP reduces profits and benefits consumers if $1 < q < \left(3 + 2\sqrt{2}\right)^{\frac{1}{1-\beta}}$.*

ii. *PP boosts profits at the expense of consumer welfare if $q > \left(3 + 2\sqrt{2}\right)^{\frac{1}{1-\beta}}$ and $\alpha_1 < \alpha < \alpha_2$.*

Proof. See the Appendix.

When the elasticity of disutility cost with respect to consumption q is sufficiently high $(\beta \rightarrow 1)$, all consumers pay lower prices under PP than under UP. PP benefits consumers at the expense of profits. In contrast, in markets where the elasticity β is sufficiently low, PP can boost profits and reduce consumer surplus. This occurs when q sufficiently high and the proportion of unit demand consumers satisfies the condition in part (ii) of Proposition 3. Figure 1 plots the region where profits are higher and consumer surplus is lower for different $\beta - values$. As β increases this region shrinks.
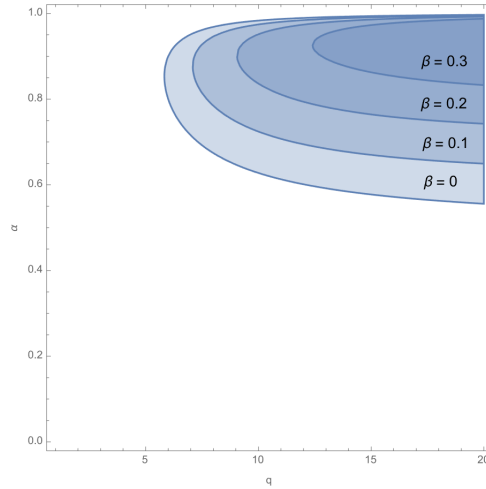

Fig. 1: Region where profits (consumer surplus) are higher (lower) with PP in comparison to UP.

Appendix

Proof of Proposition 4:

From equations (8) and (16), and making $a = q^{\beta}$

$$\pi^{UP} = \frac{1}{2} \frac{a \left(\alpha + q(1-\alpha)\right)^2}{a\alpha + q^2(1-\alpha)} \text{ and } \pi^{PP} = \frac{1}{4} \left(\alpha + a(1-\alpha)\right)$$

I obtain:

$$\pi^{UP} - \pi^{PP} = \frac{\left(a^2\alpha^2 - a^2\alpha + aq^2\alpha^2 - 2aq^2\alpha + aq^2 - 4aq\alpha^2 + 4aq\alpha + a\alpha^2 + q^2\alpha^2 - q^2\alpha\right)}{4\left(a\alpha + q^2(1-\alpha)\right)}.$$

Because $4\left(a\alpha + q^2(1-\alpha)\right) > 0$, look at the sign of the numerator.

$$\underbrace{\left((a-q)^2 + a(q-1)^2\right)}_{+}\alpha^2 + \left(4aq - 2aq^2 - a^2 - q^2\right)\alpha + aq^2 = 0.$$

Look at the sign of the discriminant $\Delta = (a-q)^2\left(a^2 - 6aq + q^2\right)$. It is negative if $\left(a^2 - 6aq + q^2\right) < 0$. Thus, $\pi^{UP} - \pi^{PPP} > 0$ if $\left(3 - 2\sqrt{2}\right)^{\frac{1}{1-\beta}} < q < \left(2\sqrt{2}+3\right)^{\frac{1}{1-\beta}}$. Since $q > 1$, then $1 < q < \left(2\sqrt{2}+3\right)^{\frac{1}{1-\beta}}$.

There are two real roots α_1 and α_2 if $\Delta > 0$, which happens when $a < \left(3 - 2\sqrt{2}\right)q$ or $a > \left(2\sqrt{2}+3\right)q$:

$$\alpha_1 = \frac{1}{(a-q)^2 + a(q-1)^2}\left(aq(q-2) + \frac{1}{2}a^2 + \frac{1}{2}q^2 + \frac{1}{2}(a-q)\sqrt{-6aq + a^2 + q^2}\right)$$

$$\alpha_2 = \frac{1}{(a-q)^2 + a(q-1)^2}\left(aq(q-2) + \frac{1}{2}a^2 + \frac{1}{2}q^2 - \frac{1}{2}(a-q)\sqrt{-6aq + a^2 + q^2}\right)$$

Hence $\pi^{UP} - \pi^{PPP} < 0$ as long as:

$$\alpha_1 < \alpha < \alpha_2 \text{ and (i) } q^\beta < \left(3 - 2\sqrt{2}\right)q \text{ or (ii) } q^\beta > \left(2\sqrt{2}+3\right)q$$

with

$$\alpha_1 = \frac{1}{(q^\beta - q)^2 + q^\beta(q-1)^2}\left(q^{\beta+1}(q-2) + \frac{1}{2}q^{2\beta} + \frac{1}{2}q^2 + \frac{1}{2}\left(q^\beta - q\right)\sqrt{q^{2\beta} - 6q^{\beta+1} + q^2}\right)$$

$$\alpha_2 = \frac{1}{(a-q)^2 + a(q-1)^2}\left(q^{\beta+1}(q-2) + \frac{1}{2}q^{2\beta} + \frac{1}{2}q^2 - \frac{1}{2}\left(q^\beta - q\right)\sqrt{q^{2\beta} - 6q^{\beta+1} + q^2}\right)$$

It is straightforward to show the condition in (ii) is never satisfied. Therefore, $\pi^{UP} - \pi^{PPP} < 0$ as long $q > \left(3 + 2\sqrt{2}\right)^{\frac{1}{1-\beta}}$ and $\alpha_1 < \alpha < \alpha_2$.∎

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