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Personalized prices in a delivered pricing model with a price sensitive demand *

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Abstract

This paper provides a first assessment of the profit and welfare effects of firms' ability to charge personalized prices where consumer demand is sensitive to price changes. In a mill pricing model, regardless of demand elasticity, personalized priicing (PP) raises consumer surplus at the expense of profits. In contrast, in a delivered pricing model, if demand is sufficiently elastic, PP boosts profits at the expense of consumer surplus and overall welfare. Moving from PP in a mill to a delivery pricing model, benefits industry profits and harms consumer surplus and welfare.

1 Introduction

The ability of firms to use big data and sophisticated information technologies to quote personalized prices has spurred active research in marketing and economics. A key issue has been to understand to what extent the practice of personalized pricing (PP) benefits firms or consumers. Since the pioneering work of Thisse and Vives (1988) on PP, a rich and diverse literature has emerged in the context of spatial Hotelling models. Spatial competition models fall into two categories: shopping (or mill pricing) models are those in which consumers pay for transport, shipping (or delivered

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pricing) models are those in which firms bear transport costs. In the past, implementing PP (especially in attribute space) has been described as unrealistic because of information and practical difficulties in distinguishing between customers, determining an individual's willingness to pay, and setting different prices to individuals. Nowadays this is no longer the case. A common feature in the personalized pricing literature is that consumers have perfectly inelastic demands (Thisse and Vives, 1988, Shaffer and Zhang, 2002, Matsumura and Matsushima, 2015).

We consider a perfect price discrimination model that differs from the existing literature in the assumption of perfectly inelastic demands. We consider a constant elasticity of substitution (CES) representative consumer model such that each consumer's demand varies with prices. Specifically, demand elasticity is $\varepsilon \in [0,1)$. Two firms are located at the extremes of the interval $[0,1]$, and consumers are uniformly distributed along this interval. The assumption that firms are competing in a unit demand framework *à la Hotelling* is widely adopted by the literature on competitive price discrimination, implying that the role of demand elasticity on the effects of competitive PP has been mostly overlooked.

This assumption may be justified by the challenge posed by introducing demand elasticity in a Hotelling framework. Anderson and De Palma (2000) introduce the CES representative consumer model into a spatial framework to analyze issues related to localized and global competition. In doing so, they allow the elasticity of demand to vary between zero and unity. Gu and Wenzel (2009, 2011) use the same system of preferences to address the optimality of firms' entry in a spatial model. Esteves and Reggiani (2014) look at behavior-based price discrimination in a mill pricing model with CES demand function. Zhang et al. (2019) endogenize firms' price discrimination decisions in this framework.

Some recent papers have looked at PP in models where firms support the transport costs.[1] In inelastic demand settings, when firms are symmetric, PP hurts firms and benefits consumers (Thisse and Vives, 1988); when firms are asymmetric, PP may benefit firms at the cost of consumers (Shaffer and Zhang, 2002)[2]. PP with delivery has also been adapted to the classic two stage location-then-pricing game to explore the effects of PP on firms' location choices.[3]

[1]See Lederer (2020) for a survey of literature on price discrimination with delivered price.

[2]In Shaffer and Zhang (2002), firms pay a targeting cost but not delivery cost. Nevertheless in their paper, consumers incur no transport when purchasing, i.e., the price quoted by consumers is delivered price.

[3]Such effects have been studied under linear consumer demand (Colombo, 2011), hyperbolic demand (Colombo, 2014), and recently a general elastic demand (Lederer, 2020). This framework is also used to study the problem of

We found that elastic demand plays a vital role in determining the effects of PP on firms' profit, consumer surplus and social welfare. Particularly, perfectly inelastic demand PP produces the same welfare outcomes in a delivery and in a mill pricing model. But when elastic demand is allowed ($\varepsilon > 0$), regardless of ε, PP boosts consumer surplus and welfare at the expense of profits if consumers pay transport costs. In contrast, in a delivery pricing model, if ε is sufficiently high, PP can boost profits at the expense of consumers and welfare. For intermediate values of ε, PP can harm profits, consumers and welfare.

2 The model

There are two firms A and B who sell competing brands of a good produced at zero marginal cost.[4] The total number of consumers in the market is normalized to one. A consumer can either decide to buy the good from firm A or B, but not from both. The two firms are located at the extremes of the interval $[0,1]$, consumers are uniformly distributed along this interval. A consumer located at $x \in [0,1]$ is at a distance $d_A(x) = x$ from firm A and at distance $d_B(x) = 1 - x$ from firm B. The cost of shipping a unit of the product to a consumer at point x is tx in case of firm A, and $t(1-x)$ in case of firm B. This transport cost can be supported by firms or consumers. To simplify we make $t = 1$. Consumers desire to buy the good from the firm which offers them the highest utility. We consider two pricing options. The first is uniform pricing, in which firm $i = A, B$ charges the same price to all consumers, p_i^{nd}. The second is personalized pricing, with mill pricing and delivered pricing. Here, we assume that information about the location of each consumer x is available to the firms. Thus, when firm i employs PP, it quotes $p_i(x)$ to each consumer located at x; consumers buy the good from the firm with the least total price.

We further assume that consumers' demand is not perfectly inelastic. Thus, the amount bought depends on the price charged. The (indirect) utility for a consumer located at x conditional on buying from firm i, $i = A, B$ is:

$$V_i = Y + v(p_i) - d_i(x) \text{ if consumers support the transport cost,}$$

products quality choices (Choudhary, et al., 2005) and collusion (Heywood, et al., 2020).

[4] The assumption of zero marginal costs can be relaxed without altering the basic nature of the results derived throughout the model.

or

$$V_i = Y + v(p_i) \text{ if firms support the transport cost}$$

where Y is the consumer income [5] and $v(p_i)$ is the consumer surplus (net of transport costs) if firm i's product is bought at price p_i. For simplicity assume that $v(p_i) = v - \frac{p_i^{1-\varepsilon}}{1-\varepsilon}$ where the reservation value v is assumed to be high enough such that all consumers purchase the good. Therefore, using Roy's identity it can be shown demand for product i is $q_i = p_i^{-\varepsilon}$, where

$$\varepsilon = -\frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i} \in [0, 1)\,.$$

is the constant elasticity of demand for firm i's product. The case with $\varepsilon = 0$ corresponds to perfectly inelastic demand. Each consumer buys one unit from the firm offering the highest surplus. For other values of ε, i.e., in the range $0 < \varepsilon < 1$, the quantity demanded responds to changes in prices although the percentage change in quantity demanded is less than the percentage change in price.

3 Benchmarks

3.1 Uniform pricing

This benchmark is useful to isolate the effects of personalized pricing on profits, consumer surplus and welfare. Let p_i^{nd} denote the uniform price of firm $i = A, B$. When consumers support transport costs, the indifferent consumer between buying from firm A and B is located at

$$\hat{x} = \frac{1}{2} + \frac{p_B^{1-\varepsilon} - p_A^{1-\varepsilon}}{2(1-\varepsilon)}.$$

Total demand for firm A and B, respectively given by D_A and D_B, now depends on market share and on the quantity per consumer. Therefore:

$$D_A = \hat{x} p_A^{-\varepsilon}, \qquad D_B = (1-\hat{x}) p_B^{-\varepsilon}, \tag{1}$$

while profits are respectively given by

$$\pi_A = \hat{x} p_A^{1-\varepsilon}, \qquad \pi_B = (1-\hat{x}) p_B^{1-\varepsilon}. \tag{2}$$

We can establish the following result.[6]

[5] We shall assume throughout that Y is high enough such that income is never a binding constraint.

[6] For the proof of Proposition 1 see Esteves and Reggiani (2014).

Proposition 1: *Under no discrimination the equilibrium price is:*

$$p^{nd} = (1-\varepsilon)^{\frac{1}{1-\varepsilon}},$$

each consumer buys:

$$q^{nd} = (1-\varepsilon)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Each firm's equilibrium profits are

$$\pi^{nd} = \frac{1-\varepsilon}{2},$$

consumer surplus is

$$CS^{nd} = Y + v - \frac{5}{4}$$

and social surplus equals

$$SS^{nd} = CS^{nd} + 2\pi^{nd} = Y + v - \varepsilon - \frac{1}{4}.$$

3.2 Personalized Pricing in mill pricing model

We consider personalized price in the context of mill pricing model. Each consumer supports the cost of shipping the good from the firm to her/his location. Let $\widetilde{p}_i(x) \geq 0$ be the price offered by firm $i = A, B$ at each point $x \in [0,1]$. The minimum price each firm can set is its marginal cost of production.[7] Consider the consumer located at x such that $x \leq \frac{1}{2}$, firm A's price for this consumer is determined as follows:

$$Y + v - \frac{[\widetilde{p}_A(x)]^{1-\varepsilon}}{1-\varepsilon} - x = Y + v - (1-x) \Rightarrow \widetilde{p}_A(x) = [(1-\varepsilon)(1-2x)]^{\frac{1}{1-\varepsilon}}.$$

Proposition 2. *When the two firms quote personalized prices and consumers support transport costs, equilibrium prices are:*

$$\widetilde{p}_A(x) = \begin{cases} [(1-\varepsilon)(1-2x)]^{\frac{1}{1-\varepsilon}} & if \quad x \leq \frac{1}{2} \\ 0 & if \quad x > \frac{1}{2} \end{cases},$$

$$\widetilde{p}_B(x) = \begin{cases} [(1-\varepsilon)(2x-1)]^{\frac{1}{1-\varepsilon}} & if \quad x \geq \frac{1}{2} \\ 0 & if \quad x < \frac{1}{2} \end{cases},$$

the consumer located at x demands $\widetilde{q}(x) = [p(x)]^{-\varepsilon}$. Each firm's profits are

$$\widetilde{\pi}_i^d = \frac{1}{4} - \frac{1}{4}\varepsilon.$$

[7] Consumer arbitrage is assumed to be prohibitively expensive.

Consumer surplus and welfare are:

$$\widetilde{CS}^d = Y + v - \frac{3}{4}$$

and

$$\widetilde{SS}^d = Y + v - \frac{1}{2}\varepsilon - \frac{1}{4}.$$

Proof. See the Appendix.

From Proposition 1 and 2: $\widetilde{\pi}_i^d - \pi^{nd} = -\frac{1}{4}(1-\varepsilon)$; $\widetilde{CS}^d - CS^{nd} = \frac{1}{2}$ and $\widetilde{SS}^d - SS^{nd} = \frac{1}{2}\varepsilon$.

Corollary 1. *In comparison to uniform pricing, PP in the context of a mill pricing model boosts consumer surplus and welfare at the expense of profits.*

As in the existing literature, when $\varepsilon = 0$ the exclusive effect of PP is to increase consumer surplus at the expense of profits.[8] Moreover, this result continues to hold with the introducing of elastic demand in a mill pricing model.

4 Personalized pricing in a delivered pricing model

Let $p_i(x)$ be the price offered by firm $i = A, B$ at each point $x \in [0,1]$. Each firm i simultaneously chooses $p_i(x) \geq 0$ for each $x \in [0,1]$. Now we assume that firms support the transport cost. To deliver the product to a consumer located at x, the shipping cost is x for firm A, it is $(1-x)$ for firm B. Under PP this is the minimum price each firm can set.

For simplicity, assume that when prices are equal, consumers buy from the closest firm. Consider a consumer located at $x \leq \frac{1}{2}$. The best firm B can do is to charge a price equal to its delivery cost, i.e., $1-x$. Thus, firm A's price for this consumer is determined as follows:

$$Y + v - \frac{[p_A(x)]^{1-\varepsilon}}{1-\varepsilon} = Y + v - \frac{(1-x)^{1-\varepsilon}}{1-\varepsilon} \Rightarrow p_A(x) = 1-x.$$

At each point $x \in [0,1]$ we have homogeneous goods Bertrand competition with asymmetric shipping costs. Hence, the firm with the lower shipping cost at x wins the consumer and the equilibrium price at x is equal to the rival's delivery cost. Thus, in equilibrium at each location $x \in [0,1]$, the firm

[8] Because all consumers buy from the nearest firm under uniform and personalized pricing, social welfare is the same in both price settings when $\varepsilon = 0$.

with the lowest delivered marginal cost makes the sale at a price equal to the second-lowest delivered marginal cost. We can establish the next proposition.

Proposition 3. *When firms support the delivery cost to each consumer, under personalized pricing the equilibrium prices are:*

$$p_A(x) = p_B(x) = \begin{cases} 1 - x & \text{if } x \in [0, 1/2], \\ x & \text{if } x \in [1/2, 1]. \end{cases}$$

the consumer located at x demands $q(x) = [p(x)]^{-\varepsilon}$. Each firm's equilibrium profits are

$$\pi^d = \frac{6 + \varepsilon - 2^{\varepsilon+1}}{8\,(2 - \varepsilon)}.$$

Consumer surplus is

$$CS^d = Y + v - \frac{1}{2}\frac{4 - 2^{\varepsilon}}{\varepsilon^2 - 3\varepsilon + 2},$$

and social surplus is

$$SS^d = CS^d + 2\pi^d = Y + v - \frac{5\varepsilon + \varepsilon^2 - 2^{\varepsilon+1}\varepsilon + 2}{4\,(\varepsilon^2 - 3\varepsilon + 2)}.$$

Proof. See the Appendix.

Before procceding it is important to stress that in the inelastic demand case ($\varepsilon = 0$), profits, consumer surplus and welfare under PP are exactly the same under mill or delivery pricing models. This is no longer true when $\varepsilon > 0$.

5 Profit and welfare effects

The effects of personalized pricing in a delivered pricing model *vis à vis* uniform pricing can now be evaluated. Taking into account profits, consumer surplus and social welfare under the two pricing policies, we can establish the following results.

Using Proposition 1 and 3 yields

$$\pi^d - \pi^{nd} = \frac{1}{8\,(2 - \varepsilon)}\left(13\varepsilon - 4\varepsilon^2 - 2^{\varepsilon+1} - 2\right). \tag{3}$$

$$CS^d - CS^{nd} = \frac{1}{4\,(1 - \varepsilon)\,(2 - \varepsilon)}\left(5\varepsilon^2 - 15\varepsilon + 2^{\varepsilon+1} + 2\right). \tag{4}$$

$$SS^d - SS^{nd} = \frac{1}{2} \frac{\varepsilon}{(1-\varepsilon)(2-\varepsilon)} \left(-6\varepsilon + 2^\varepsilon + 2\varepsilon^2\right). \tag{5}$$

Corollary 2. *In the perfectly inelastic case, moving from no discrimination to personalized pricing harms industry profits, boosts consumer surplus and has no effect on social welfare.*

The proof of this corollary is straightforward, we can show that at $\varepsilon = 0 : \pi^d - \pi^{nd} = -\frac{1}{4}$, $CS^d - CS^{nd} = \frac{1}{2}$ and $SS^d - SS^{nd} = 0$.

Corollary 3. *When $\varepsilon \in (0,1)$, in comparison to no discrimination:*

(i) profits are higher with personalized pricing if $0.4099 < \varepsilon < 1$, otherwise the reverse happens.

(ii) consumer surplus falls with personalized pricing if $0.3409 < \varepsilon < 1$, otherwise consumer surplus increases.

(iii) welfare falls with personalized pricing if $0.20654 < \varepsilon < 1$, otherwise welfare increases.

The reason for this result is that the uniform price and mill pricing with PP decrease with ε, while the delivery price with PP is independent of that. Moving from uniform price to PP with delivery thus has two effects. First, it intensifies competition which reduces equilibrium price. This effect exists in both delivery pricing and mill pricing. Second, it removes the dependency of price on elasticity. An increase in elasticity thus will reduce the uniform price but not the delivery price under PP. That is, relaxing the assumption of perfect inelastic demand activates the second effect, which outweighes the first one, when the elasticity is large, and reverses the results under the assumption of perfect inelastic demand.

6 Concluding remarks

In a mill pricing model, regardless of ε, PP boosts consumer surplus and welfare at the expense of profits. In contrast, in a delivery pricing model, PP can raise profits at the expense of consumer surplus and welfare. Firms can use PP in a profitable way as long as the elasticity of demand is sufficiently high. For intermediate values of $0.3409 < \varepsilon < 0.4099$, PP is bad for firms, consumers and welfare. Only when ε is low enough, PP can boosts consumer surplus and welfare at the expense of profits.

Finally, comparing PP in both pricing models we find that for $0 < \varepsilon < 1$, $\pi^d - \widetilde{\pi}_i^d > 0$, $CS^d - \widetilde{CS}^d <$

0 and $SS^d - \widetilde{SS}^d < 0$, suggesting that moving from PP in a mill pricing model to PP in a delivery one, benefits industry profits and harms consumers and welfare.

Appendix

This Appendix collects the proofs omitted from the text.

Proof of Proposition 2: Under mill pricing when the two firms quote personalized prices, firm A and B price schedule is given by

$$p_A(x) = \begin{cases} [(1-\varepsilon)(1-2x)]^{\frac{1}{1-\varepsilon}} & if \quad x \leq \frac{1}{2} \\ 0 & if \quad x > \frac{1}{2} \end{cases}$$
$$p_B(x) = \begin{cases} [(1-\varepsilon)(2x-1)]^{\frac{1}{1-\varepsilon}} & if \quad x \geq \frac{1}{2} \\ 0 & if \quad x < \frac{1}{2} \end{cases}$$

and the consumer located at x buying from firm i demands $q_i(x) = p_i(x)^{-\varepsilon}$, $i = A, B$. Profits given x are:

$$\pi_A(x) = \begin{cases} (1-\varepsilon)(1-2x) & if \quad x \leq \frac{1}{2} \\ 0 & if \quad x > \frac{1}{2} \end{cases}$$
$$\pi_B(x) = \begin{cases} (1-\varepsilon)(2x-1) & if \quad x \geq \frac{1}{2} \\ 0 & if \quad x < \frac{1}{2} \end{cases}$$

Each firm profits are

$$\pi_A^D = \int_0^{\frac{1}{2}} \pi_A(x)dx = \frac{1}{4} - \frac{1}{4}\varepsilon.$$
$$\pi_B^D = \int_{\frac{1}{2}}^1 \pi_B(x)dx = \frac{1}{4} - \frac{1}{4}\varepsilon.$$

Consumer surplus is

$$CS^d = 2\int_0^{\frac{1}{2}} V_A dx = 2\int_0^{\frac{1}{2}} (Y + v - \frac{(1-\varepsilon)(1-2x)}{1-\varepsilon} - x)dx$$
$$= Y + v - \frac{3}{4}$$

Social surplus is

$$SS^d = CS^d + 2\pi^d = Y + v - \frac{1}{2}\varepsilon - \frac{1}{4}.$$

Proof of Proposition 3: Firm A and B profits given x are:

$$\pi_A(x) = \begin{cases} (1-x)^{1-\varepsilon} - x & if \quad x \leq \frac{1}{2} \\ 0 & if \quad x > \frac{1}{2} \end{cases}$$

$$\pi_B(x) = \begin{cases} x^{1-\varepsilon} - (1-x) & if \quad x \geq \frac{1}{2} \\ 0 & if \quad x < \frac{1}{2} \end{cases}$$

$$\begin{aligned} \pi^d &= \int_0^{1/2} \pi_A(x)dx = \int_0^{1/2} ((1-x)^{1-\varepsilon} - x)dx \\ &= \frac{\varepsilon - 2 \times 2^{\varepsilon} + 6}{8(2-\varepsilon)} \end{aligned}$$

$$\begin{aligned} CS^d &= 2\int_0^{1/2} V_A f(x)dx \\ &= Y + v + \frac{1}{2}\frac{2^{\varepsilon} - 4}{\varepsilon^2 - 3\varepsilon + 2} \end{aligned}$$

$$\begin{aligned} SS^d &= CS^d + 2\pi^d \\ &= Y + v - \frac{1}{4(\varepsilon^2 - 3\varepsilon + 2)}\left(5\varepsilon + \varepsilon^2 - 2 \times 2^{\varepsilon}\varepsilon + 2\right) \end{aligned}$$

$$\pi^{nd} = \frac{1-\varepsilon}{2},$$

consumer surplus is

$$CS^{nd} = Y + v - \frac{5}{4}$$

and social surplus equals

$$SS^{nd} = CS^{nd} + 2\pi^{nd} = Y + v - \varepsilon - \frac{1}{4}.$$

Proof of Corollary 3. From equations (3), (4) and (5): $\pi^d - \pi^{nd} \geq 0$ iff $0.40997 \leq \varepsilon < 1$, otherwise $\pi^d - \pi^{nd} < 0$. $CS^d - CS^{nd} \geq 0$ iff $0 < \varepsilon \leq 0.340\,97$. Finally, $SS^d - SS^{nd} \geq 0$ so long as $-6\varepsilon + 2^{\varepsilon} + 2\varepsilon^2 \geq 0$, which implies $0 < \varepsilon \leq 0.20654$.

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