# Personalized Pricing and Competition

Andrew Rhodes Jidong Zhou

TSE & Yale SOM

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# Introduction

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This paper studies the welfare impact of (banning) **personalized pricing**

- Focus on **first-degree price discrimination**, as an approximation of very fine-tuned third-degree price discrimination
- Big data and sophisticated pricing algorithms make it increasingly relevant

"The increased availability of behavioral data has also encouraged a shift from *third-degree price discrimination* based on broad demographic categories towards *personalized pricing*."

— Council of Economic Advisers, 2015

"Fully personalized pricing is unrealistic, but prices based on fine grained features of consumers may well be feasible, so the line between *third degree* and *first degree* is becoming somewhat blurred."

— Varian, 2018

## Is personalized pricing happening?

Plenty of anecdotal evidence of personalized pricing based on geolocation, income, browsing history, loyalty, etc. (see, e.g., OECD, 2018) Deloitte survey

Relatively limited formal evidence so far

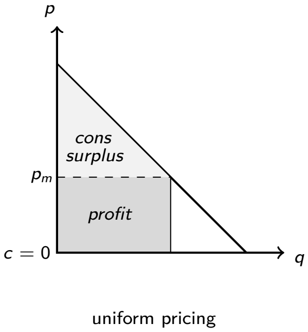
- E.g., Hannak et al. (2014), Aparicio et al. (2021), Shiller (2021)
- **Firms often disguise personalized pricing to avoid consumer backlash** (e.g., by offering individualized discounts by email or smartphone app)

Lots of policy discussion (e.g., CEA, 2015; OECD, 2018; EC, 2018)

- Which consumers gain and which ones lose?
- Aggregate impact on consumer welfare and firm profit?
- How does data asymmetry across firms affect market performance?

## What is known about the impact of personalized pricing?

The textbook **monopoly** case:

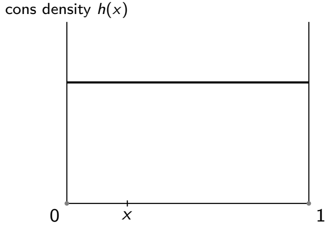


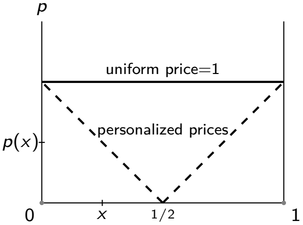

**Personalized pricing improves total welfare,**

**but redistributes surplus from consumers to firms**

# What is known about the impact of personalized pricing?

The **Hotelling duopoly** case (Thisse and Vives, 1988, *AER*):




*uniform* distribution

$v_0(x) = V - x$ if buy from firm 0

$v_1(x) = V - (1 - x)$ if buy from firm 1

uniform price: $1/h(\frac{1}{2}) = 1$

personalized prices:

$p(x) = v_0(x) - v_1(x) = 1 - 2x \leq 1$

**Personalized pricing intensifies competition,**

**harms firms, and benefits every consumer**

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Competition completely reverses the welfare impact. But is this true in general?

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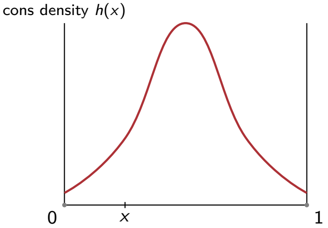


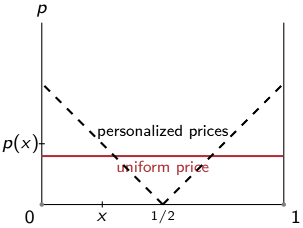


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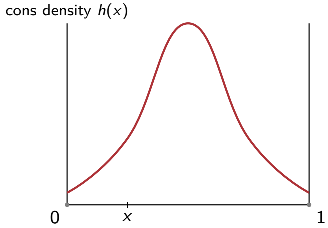


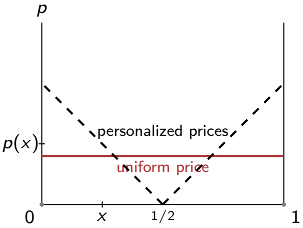


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$p(x) = v_0(x) - v_1(x) = 1 - 2x$

**Does personalized pricing still harm firms**
**and benefit consumers (in aggregate)?**

## What do we do in this paper?

- Revisit the impact of personalized pricing in a general oligopoly framework
  - allow for more firms, partial market coverage, and more general valuation distribution (nest monopoly and Hotelling as special cases)
- Harm firms and benefit consumers if market coverage is high; impact is *reversed* if market coverage is low (e.g., when cost is high)
- Data asymmetry across firms can be the worst case for consumers compared to symmetric cases
- In a free-entry market, personalized pricing tends to benefit consumers by inducing socially optimal entry

# Some related literature

The existing literature on price discrimination mainly focuses on second- or third-degree price discrimination (e.g., Varian, 89; Armstrong, 07; Stole, 07)

Growing research on personalized pricing:

- *Theory*: Chen and Iyer (02), Shaffer and Zhang (02), Montes et al. (19), Ichihashi (20), Chen et al. (21), Ali et al. (23), Anderson et al. (23), etc.
- *Empirical*: Waldfogel (15), Shiller (20), Kehoe et al. (20), Dube & Misra (23), etc.

# The model

- $n$ competing firms, each supplying a differentiated product at unit cost $c$
  - e.g., hotels, electronics, furniture, etc.

- A unit mass of consumers, each wishing to buy at most one product
  - they know their valuations for the $n$ products: $\boldsymbol{v} = (v_1, \ldots, v_n) \in [\underline{v}, \overline{v}]^n$
  - distributed according to an *exchangeable* joint cdf $\tilde{F}(\boldsymbol{v})$ in the population (so firms are *ex ante symmetric*)
  - they have an outside option with a normalized payoff 0

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  - they have an outside option with a normalized payoff 0
- Two pricing regimes (or information structures):
  - **uniform pricing**: firms have no access to consumer data, so each offers the same price to all consumers
  - **personalized pricing**: firms observe each consumer's $\boldsymbol{v} = (v_1, ..., v_n)$, and offer them personalized prices accordingly (an alternative information structure: firm $i$ only observes $v_i$)

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- In each regime, firms set prices simultaneously; consumers observe prices and then choose the best option $\max\{0, v_1 - p_1, \ldots, v_n - p_n\}$

## Uniform pricing equilibrium

- Let $H_z(x)$ be the CDF of relative preference $x_z \equiv v_i - z - \max_{j \neq i}\{0, v_j - z\}$
- Assume $1 - H_z(x)$ **is log-concave in** $x$**, and** $\frac{1-H_z(0)}{h_z(0)}$ **is non-increasing in** $z$
- There is then a unique symmetric equilibrium price $p$ which solves

$$p - c = \frac{1 - H_p(0)}{h_p(0)} \ ,$$

- Consumers buy the *best* product at price $p$ or take the outside option, so (aggregate) consumer surplus is

$$V_U = \mathbb{E}[\max\{0, v_{n:n} - p\}]$$

- All consumers buy iff $p \leq \underline{v} \Leftrightarrow c \leq \hat{c}(n, \tilde{F})(< \underline{v})$

demand details

## Personalized pricing equilibrium

- Standard (asymmetric) Bertrand competition for each consumer
- Ignore equilibria where some firms charge prices below cost; all other equilibria are outcome equivalent to the following one:
  - a firm wins a consumer iff its product is her favorite and is valued above cost
  - each "losing" firm charges $c$
  - the "winning" firm (say, $i$) charges price $p_i$ such that

$$v_i - p_i = \max_{j \neq i}\{0, v_j - c\} \ ,$$

- Consumer surplus is *as if* consumers buy the *second best* product at price $c$ or take the outside option, so

$$V_D = \mathbb{E}[\max\{0, v_{n-1:n} - c\}]$$

- All consumers buy iff $c \leq \underline{v}$ (a weaker cond. than under uniform pricing)

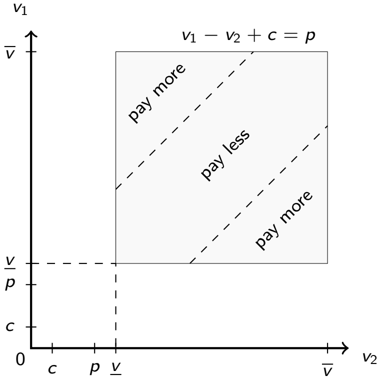
# Impact with full market coverage

**Proposition** 1 (A generalization of Thisse and Vives, 1988)

*For $n \geq 2$, suppose $c \leq \hat{c}(n, \tilde{F})$ (so that the market is fully covered under uniform pricing). Then relative to uniform pricing, personalized pricing harms firms and benefits consumers (in aggregate), but has no impact on total welfare.*

Proof

# Graphic intuition




consumer $(v_1, v_2)$ pays $|v_1 - v_2| + c$ under personalized pricing

- The assumed log-concavity condition ensures that there are sufficiently many consumers with weak preferences in the "pay less" area
- Richer consumers do not always pay more under personalized pricing

# Impact with partial market coverage

Suppose now that economic primitives are such that *not* all consumers buy under uniform pricing (i.e., $c > \hat{c}(n, \tilde{F})$)

- Personalized pricing enhances total welfare by expanding demand
- **Its impact on firms and consumers can now be completely reversed**

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An exponential-distribution example first:

**Observation**

*In the i.i.d. exponential case, relative to uniform pricing, personalized pricing benefits firms and harms consumers whenever the market is not fully covered under uniform pricing. (Under full coverage, no impact on firms or consumers.)*

Proof

## Impact with partial market coverage

- For more general distributions, analytical results available when $c$ is large (so that market coverage is low):

**Proposition 2**

*If $f(\overline{v}) > 0$, or in the i.i.d. case with a log-concave $f(v)$, there exists $\bar{c}$ such that when $c > \bar{c}$, personalized pricing benefits firms and harms consumers. More precisely,*

$$2 \leq \lim_{c \to \overline{v}} \frac{\Pi_D}{\Pi_U} \leq e \quad \textit{and} \quad \lim_{c \to \overline{v}} \frac{V_D}{V_U} = 0 \ .$$

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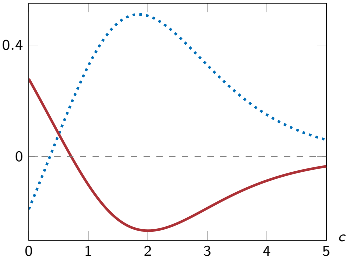
- Or for a family of distributions in the duopoly case:

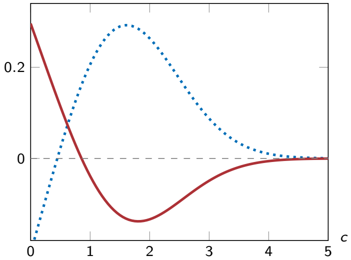
**Proposition 3**

*In the i.i.d. duopoly case with a generalized Pareto distribution, the impact of personalized pricing takes a cut-off format when $c$ varies.*

# Numerical examples: impact and production cost




Extreme value

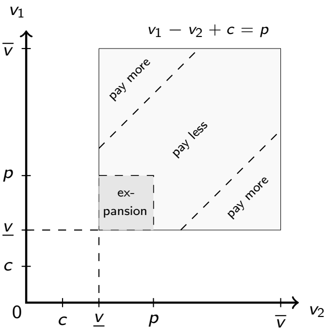



Normal

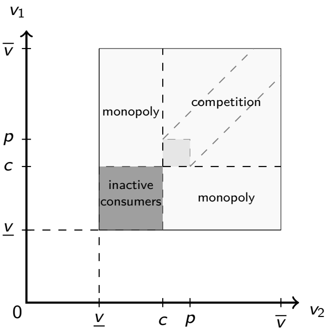
i.i.d. case with different consumer valuation distributions ($n = 2$)
(Dotted lines: impact on industry profit; Solid lines: impact on consumer surplus)

A cut-off result suggested: (i) Thisse-Vives when $c$ is small; (ii) opposite when $c$ is large; (iii) both firms and consumers benefit when $c$ is intermediate.
(with Extreme value, personalized pricing harms consumers if market coverage is less than 82%)

# Graphic intuition



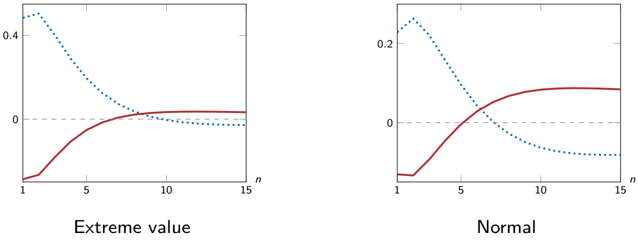

The case of $c < \underline{v}$:
pass-through effect; the pay-more regions expand as $c$ increases




The case of $c > \underline{v}$:
"monopoly segments" emerge; they become more important as $c$ increases

In the limit as $c \to \overline{v}$, each firm acts almost like a monopolist.

# Numerical examples: impact and the number of firms




i.i.d. case with different consumer valuation distributions ($c = 0$)

(Dotted lines: impact on industry profit; Solid lines: impact on consumer surplus)

Similar cut-off result suggested; **personalized pricing can be anti-competitive for a significant range of $n$.**

(with Extreme value, personalized pricing benefits firms if $n < 10$ and harms consumers if $n < 7$)

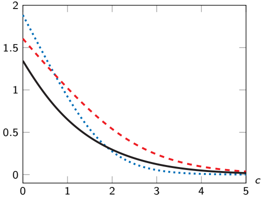
## Asymmetrically informed firms

- The "mixed" case: some firms have more data and better technologies
  - $k$ firms can do personalized pricing, while $n - k$ firms cannot
  - suppose the $n - k$ firms move first and simultaneously set uniform prices
  - observing this, the $k$ firms then simultaneously set personalized prices

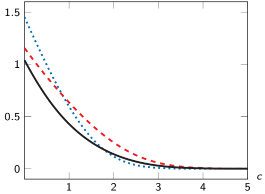
- When $c$ is high (so market coverage is low), this "mixed" case is ranked in between the two symmetric case

- When $c$ is low (so market coverage is high), however, this "mixed" case tends to be the worst for total welfare and consumer surplus, but the best for industry profit
  - the $k$ firms can use low personalized prices to "poach" consumers and induce them to buy even if their products are not the best match
  - this **match inefficiency** tends to dominate when market coverage is high
  - so forcing large firms to share data or set uniform prices can be desirable

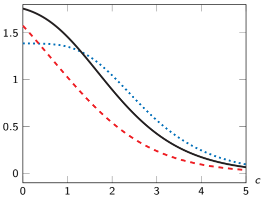
# Asymmetrically informed firms



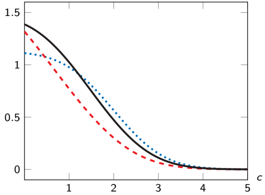

Consumer Surplus (Extreme value)




Consumer Surplus (Normal)




Industry Profit (Extreme value)




Industry Profit (Normal)

Asymmetric case versus symmetric cases for different values of $c$

($n = 2$; dashed lines: $k = 0$; solid lines: $k = 1$; dotted lines: $k = 2$.)

# Impact of personalized pricing in a free-entry market

Personalized pricing may also affect market structure in the long run

- Consider now a free-entry market:
  - firms first decide whether to enter the market by paying an entry cost
  - then compete in prices after entering
  - equilibrium is determined by the usual *zero-profit* condition

**Proposition** 4

*Suppose a new entrant does not affect valuations for existing products.*

*(i) The free-entry outcome under personalized pricing is socially optimal.*

*(ii) Personalized pricing then outperforms uniform pricing for consumers (if integer constraint is ignored).*

- With personalized pricing, new entrant extracts all the surplus it brings to the market, so its entry incentive is perfectly aligned with social planner's

# Conclusion

This paper offers a general oligopoly framework for studying the impact of (competitive) personalized pricing

- Harm firms and benefit consumers if market coverage is high; but the opposite if market coverage is low
- The case of asymmetrically informed firms can be the worst for consumers
- In a free-entry market, personalized pricing tends to induce socially optimal market structure and so benefit consumers

Ongoing work: consumer privacy choice and data sharing externality

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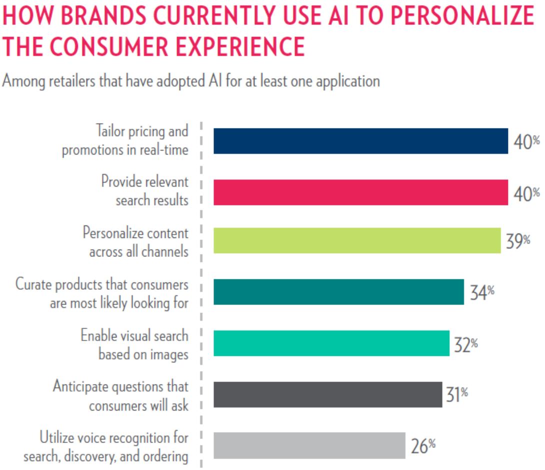
**Thank You!**

# Is personalized pricing happening?




*Source*: Deloitte report (2018) on "consumer experience in the retail renaissance"

# Demand under uniform pricing

- Let $x_z \equiv v_i - \max_{j \neq i}\{z, v_j\}$ denote the *relative preference for product i*
- Let $H_z(x)$ and $h_z(x)$ be its cdf and pdf, respectively
- Firm $i$'s demand, if it sets price $p_i$ while others stick to $p$, is

$$\Pr[v_i - p_i > \max_{j \neq i}\{0, v_j - p\}] = \Pr[\underbrace{v_i - \max_{j \neq i}\{p, v_j\}}_{x_p} > p_i - p] = 1 - H_p(p_i - p)$$

**Assumption 1**

$1 - H_z(x)$ *is log-concave in* $x$*, and* $\frac{1 - H_z(0)}{h_z(0)}$ *is non-increasing in* $z$*.*

Some *sufficient* primitive conditions:

- the first holds if $\tilde{F}$ has log-concave joint density (Caplin and Nalebuff, 91)
- both hold in the i.i.d. case where each $v_i$ has log-concave density

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# Proof of Proposition 1

- Under full coverage, only relative preference $x = v_i - \max_{j \neq i}\{v_j\}$ matters
- Let $H(x)$ and $h(x)$ be the cdf and pdf of $x$
- Then each firm's profit under personalized pricing is $\int_0^\infty [1 - H(x)]dx$, and that under uniform pricing is $\frac{[1-H(0)]^2}{h(0)}$
- The assumed log-concavity of $1 - H(x)$ implies that

$$\int_0^\infty [1-H(x)]dx = \int_0^\infty \frac{1 - H(x)}{h(x)} dH(x) \leq \int_0^\infty \frac{1 - H(0)}{h(0)} dH(x) = \frac{[1 - H(0)]^2}{h(0)}$$

- Given personalized pricing has no impact on total welfare, the impact on consumers is just the opposite

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# An exponential example

Suppose $v_i$'s are independent and each has cdf $F(v) = 1 - e^{-(v-\underline{v})}$ on $[\underline{v}, \infty)$

- Equilibrium uniform price is $p = 1 + c$, *regardless of market coverage*

Profit comparison:

- Industry profit under uniform pricing is $1 - F(p)^n = 1 - F(1+c)^n$
- Industry profit under personalized pricing is

$$\int_c^{\overline{v}} \frac{1 - F(v)}{f(v)} dF(v)^n = 1 - F(c)^n$$

- **Personalized pricing boosts profit (whenever $1 + c > \underline{v}$)!**

Consumer surplus comparison:

- Consumer surplus is lower under personalized pricing iff

$$\underbrace{\int_c^{1+c} (v - c) dF(v)^n}_{\text{total welfare improvement}} < \underbrace{F(1+c)^n - F(c)^n}_{\text{boosted profit}},$$

  and this inequality is clearly true

- **Personalized pricing harms consumers (whenever $1 + c > \underline{v}$)!**

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