Dynamic Competition in the Era of Big Data

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Policy Concern of Personalized Pricing

• With advent of Big Data/AI, major policy concern is firms in online markets
  ○ access to granular sensitive info about individual consumers
  ○ may exploit this advantage through advanced algorithms
  ○ can price discriminate across consumers, extracting more of WTP

• Is concern warranted? That is, are consumers (surplus) and society (total welfare) harmed by these forms of personalized pricing?

• We argue this question all the more important
  ○ for experience goods of multiproduct firms

Next: why?
Experience Goods and Multiproduct Firms

• In case of experience goods: consumers uncertain about tastes
  ○ gain information only by consuming
  ○ taste reflects persistent idiosyncratic matches of consumer with products

• In general firms offer *multiple differentiated products*
  ○ consumer’s taste may be correlated across a firm’s products (Apple)
  ○ pricing of one product affects consumer’s future purchases of all products

• Through their pricing, firms not only directly compete to attract consumers, but also strategically *manage information flow* (directly to consumers and indirectly to their competitors)
  ○ induces consumers to buy more/less informative goods about their tastes
  ○ shapes consumers’ perception of their tastes and future demand
A Review of Some Personalized Pricing Results

• Monopoly, first-degree price discrimination
  ○ efficient (eliminates deadweight loss from uniform price monopoly)
  ○ hurts consumers relative to uniform price ⇒ consumers get no surplus

• What about when there is competition?
  ○ Thisse and Vives (1988) (next slides)
Competition on a Hotelling Line

- Symmetric firms, A and B, with marginal costs $c$
- Consumers face transport cost $t$, have types $\theta \sim U[0, 1]$
- Utility: $v - t\theta - p_A$ if buy from A
Uniform Pricing Rule

- With uniform pricing, both firms charge \( p^* = c + t \)
Personalized Prices: Thisse and Vives (1988)

- Personalized prices lower for ALL consumers
- Firm A charges $p^*_A(\theta) = c + t(1 - 2\theta)$
- Not necessarily inefficient
But What If Firms Can *Influence* Consumer’s Type?

- Through dynamic pricing of experience goods, firms can influence a consumer’s location on the line.
- Consumer tastes move as consumer *learns*.
- What will dynamic prices/competition look like?
But What If Firms Can Influence Consumer’s Type?

- What are implications for efficiency? Consumer surplus?
- Experience goods + learning = just one microfoundation for this type of dynamic, endogenous switching cost.
Related Paper: Bergemann and Välimäki (1996)

- Bergemann and Välimäki (1996) established surprising result
  - thinking at the time: info is *publicly observed* and produced at an opportunity cost ⇒ info is a public good and will be underprovided (inefficient)
  - BV 1996 show equilibrium is efficient in single-product duopoly

- BV result turns out *not* to be general

- We extend BV model to case of *multiproduct* firms:
  - firms may induce consumer (through prices) to buy *wrong* product from social planner’s point of view
  - results in underprovision or overprovision of information by firms to increase profits

- We extend BV model to *oligopoly*:
  - with experience goods, ↑ competition can have perverse effects
  - competition does not internalize preferences of all firms over who selling firm is (and hence what the consumer learns)
  - evaluation of performance of these markets subtle
Our paper

• Model of experience goods:
  ○ consumers uncertain about fit of brand, have a belief evolving with each purchase experience
  ○ multiple multiproduct firms/brands competing
  ○ firms observe each consumer’s purchase history/experience, offer personalized price

• Empirical Analysis: Apple vs. Samsung phones/tablets
  ○ estimate demand under uniform pricing (real world); simulate competitive personalized pricing

• Questions:
  ○ is personalized pricing efficient?
  ○ are consumers/firms better or worse off than in uniform pricing?
Model
Market

• Market populated by two firms $f = A, B$ (consistent with application)
  ◦ paper: also covers $n > 2$ firms case

• Each firm produces multiple products

• Compete in infinite horizon in discrete time; discount factor $\delta$

Model can be generalized in many directions; we focus on most parsimonious version that still yields rich results
Consumers

• Nature assigns each consumer as a *good* or *bad* match for each firm/brand $f$ held fixed over time

• Consumer has prior $\pi_t = (\pi_t^A, \pi_t^B)$ about goodness of match with each firm
  ○ consumer doesn’t know *true taste*, only prior
  ○ firms observe personal data of consumer (purchase history, experiences) $\Rightarrow$ firms know how prior evolves

• No private information in this model
Market of Multi Product Firms

- Marginal cost = 0 zero for simplicity

- Firm $f$ sells multiple products/varieties, each leading to stochastic experience (good/bad outcome)

- For product $k$
  - good outcome yields $X^H_k$ today
  - bad outcome yields $X^L_k$ today

- Can have good/bad outcome whether or not consumer is truly a good/bad match
  - $\alpha_k$: prob. of good outcome if consumer truly a good match
  - $\beta_k$: prob. of good outcome if consumer truly a bad match

- A product/variety consists of $(X^H_k, X^L_k, \alpha_k, \beta_k)$
Informativeness of Varieties About Taste

- Start with prior $\pi^f_0$ about firm $f$ with $\alpha_k \geq \beta_k$
  - if experience $X^H_k$ then posterior about taste for $f$’s products is high
    \[
    \pi_1^f(k) = \frac{\alpha_k \pi_0^f(k)}{\alpha_k \pi_0^f(k) + \beta_k (1 - \pi_0^f(k))} \geq \pi_0^f(k)
    \]
  - if experience $X^L_k$ then posterior about taste for $f$’s products is low
    \[
    \pi_1^f(k) = \frac{(1 - \alpha_k) \pi_0^f(k)}{(1 - \alpha_k) \pi_0^f(k) + (1 - \beta_k) (1 - \pi_0^f(k))} \leq \pi_0^f(k)
    \]
- Both the consumer and the firms face potential trade-off between current payoff and gaining information
Expected Utility From Variety $k$ of Firm $f$

- Recall $\pi^f_t = \text{prior at beginning of } t \text{ that a given consumer is good match for firm } f$

- For variety $k$, the probability of a good outcome is

$$\gamma_k(\pi^f_t(k)) = \pi^f_t(k) \alpha_k + (1 - \pi^f_t(k)) \beta_k$$

- Expected utility today from purchasing variety $k$ is

$$\underbrace{X^H_k \gamma_k(\pi^f_t(k)) + X^L_k (1 - \gamma_k(\pi^f_t(k))) - p_k}_{u_k(\pi^f_t(k), k)}$$
Strategies and Payoffs Under Price Discrimination

Firms

• Without loss, can consider competition for one consumer at a time
• Firms’ objective: maximize present discounted value of profits
• Each firm offers one-period contract \((k, p)\): variety and price
• Without loss, firm “picks” variety it prefers consumer to choose

Consumers

• Consumer’s objective: maximize present discounted value of utility
• Consumer chooses which product to buy each period
Timing, Events and Equilibrium

Timing

• For a given consumer, nature chooses good/bad match for each firm held fixed throughout time

• Each period
  1. firms simultaneously make offers
  2. consumer accepts at most one offer
  3. utility realized ($X^H_k$ or $X^L_k$)
  4. prior $\pi_t = (\pi^A_t, \pi^B_t)$ updated to $\pi_{t+1} = (\pi^A_{t+1}, \pi^B_{t+1})$

Focus on Markov perfect equilibrium

• History summarized by current prior $\pi_t = (\pi^A_t, \pi^B_t)$

• Strategies satisfy consumer and firm optimality

• Perfection requirement is extension of that in Bergemann and Välimäki (1996) (pins down pricing strategy for the firm the consumer doesn’t buy from)
Markov Perfect Equilibrium: Intuition

• Firm optimality implies consumer always indifferent between two firms

• Firm optimality typically yields trade-off between current profit and information
  ○ firm $f$ values information generated by competitor
  ○ may want to lose to firm $f'$ to observe experience from $k_{f'}$
  ○ so as to attract consumer in future periods at higher profits

• Consumer optimality implies
  ○ consumer might not accept offer with lowest price/highest static utility
  ○ price paid must compensate for differences in learning across products
Markov Perfect Equilibrium: Intuition

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- Consumer optimality implies
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  - price paid must **compensate** for differences in learning across products

Key to equilibrium pricing rule
Pricing
Bellman Equations for Firms and Consumer

**Firm**
Firm A’s strategy is \((k_A, p_A)\), a product and price, satisfying

\[
V^A(\pi) = \max_{k_A, p_A} \left\{ d_A \left[ p_A + \delta EV^A(\pi'|\pi, k_A) \right] + d_B \delta EV^A(\pi'|\pi, k_B) \right\}
\]

\(d_A \in \{0, 1\}, d_B \in \{0, 1\}\) is consumer’s strategy to buy from A/B

**Consumer**
Consumer’s strategy satisfies

\[
U(\pi) = \max_{f \in \{A, B\}} \left\{ u_f(\pi^f, k_f) - p_f + \delta EU(\pi'|\pi, k_f) \right\}
\]

**Match value**
*Match value* of consumer and firm \(f\) given by

\[
W^f(\pi) = V^f(\pi) + U(\pi)
\]
Dynamic Pricing Rule: Three steps

First, winning firm (say A) charges price so that consumer is just indifferent between A and B:

\[ u_A(\pi^A, k_A) - p_A + \delta EU(\pi' | \pi, k_A) = u_B(\pi^B, k_B) - p_B + \delta EU(\pi' | \pi, k_B) \]

Second, losing firm is indifferent between not selling and selling (cautious equilibrium refinement of BV):

\[ p_B + \delta EV^B(\pi' | \pi, k_B) = \delta EV^B(\pi' | \pi, k_A) \]

Third, solve second equation for \( p_B \) and substitute into first equation:

\[ p_A(\pi) = u_A(\pi^A, k_A) - u_B(\pi^B, k_B) + \delta \left[ EW^B(\pi' | \pi, k_A) - EW^B(\pi' | \pi, k_B) \right] \]

where \( W^f(\pi) = V^f(\pi) + U(\pi) \) (match value)
Dynamic Pricing Rule

- Price charged by selling firm, firm $A$, is
  \[ p_A(\pi) = u_A(\pi^A, k_A) - u_B(\pi^B, k_B) \]
  \( \text{difference in static utility between products} \)
  \[ + \delta \left[ EW^B(\pi' | \pi, k_A) - EW^B(\pi' | \pi, k_B) \right] \]
  \( \text{compensating differential for foregone information about } B \)

- Intuition: consumer compensated for lost information about non-selling firm
  - compensating price differential negative (can be positive w/ correlation)
  - more negative the more informative the competitor’s offered variety
  - leads to frequent price discounts in equilibrium as consumer’s prior evolves
Equilibrium Can Be Inefficient: BV 1996 Breaks Down

- Bergemann and Välimäki (1996) efficiency result breaks down with multiproduct firms or $n > 2$ firms

- Why? Firms do not internalize impact on competitor’s future ability to sell its brand to the consumer
  - may pick “wrong” product from planner’s point of view
  - may underprovide or overprovide information to increase future profits
  - competition does not internalize preference of all firms over who selling firm is (and hence what the consumer learns)

- Linear prices limit efficiency: firms compete in (linear) prices but sell bundles of utility and information
  - linear price insufficient to support efficient allocation
Empirical Analysis
What Would Happen in Practice?

• Model shows there is scope for inefficiency

• Also clear scope for consumer surplus to decrease or increase
  ○ for some consumers, competition is *intensified*
  ○ for others, strong tastes exploited

• What happens in practice—to prices, profits, consumer surplus and welfare—if firms use dynamic personalized pricing?
How Would Apple/Samsung Personalized Pricing Affect Efficiency and Consumer Surplus?

- eBay data on \( \approx \) 1M purchases of new-in-box smartphones/tablets

- Focus on Apple and Samsung
  - two world largest smartphone producers
  - large players in tablet market as well

- Over period 2014–2017, we observe
  - product and brand id (phones/tablets of Apple, Samsung, other brands)
  - buyer’s id (to track buyers across purchases)
  - buyer’s product rating (for subset of data)

- Important: we are not studying eBay seller behavior
  - use eBay data to estimate demand and information parameters
  - in the non-price-discrimination world
Tastes for Apple/Samsung
Learning whether you are an “Apple person” or “Samsung person”

Is it worth $1K?

Phone. Would I recommend, yes and no, but more yes. If you are an Apple person, buy it. At this price point, if you are an Android person, there is probably a better phone in the Android universe for you. This review is from Apple · iPhone X 64GB · Space Gray (Verizon)

Samsung to iPhone

Was a Samsung guy since the Galaxy S4, bought a Note 8 when it launched. I found myself tired of constant apps quitting, slow speed, and other minor errors. Decided to grab an iPhone X and I can go on and on about how impressed I am, the new iPhone X and the operating system blows Android away.

Impressed ★★★★★ tkvas · 1 year ago

I have loved this phone. While the price tag is heavy, it is easily the best phone I’ve ever owned. I have been a Samsung person since day one, but have always owned other Apple products such as iPod Touch and Macs. Hands down, I think this phone out-performs the iPhoneX. The camera is absolutely p (read more)

Good & Bad !?!

Reviewed in the United States on December 10, 2018
Style: Wi-Fi | Color: Space Gray | Size: 32GB | Verified Purchase

If you like Apple, you will like it. If you are not an Apple person, and are used too Android and “OK Google,” you may not like it. I love Windows and its problems, then Andorid, and I love the iPhone. I am not a Samsung person, I just bought one recently.

Mammoth Mobiles Ltd

Are you a “Samsung person” or an “Apple person”? Either way, this Samsung Galaxy S8 is a great phone and definitely worth checking out!

We currently have two available in brand new refurbished condition (with genuine service Samsung parts). Don’t forget, all devices include 6 months warranty.

Aphinya Dechalert 4 days ago · 5 min read

I’m not affiliated with Apple. I’m not an Apple person. I’ve never been an Apple person. But a few months ago, I got an iPad and thought heck, I
Data

- Lump all Apple/Samsung phones/tablets into 4 “products”
  - purchase of non-Apple/Samsung product is outside option

- Only need two purchases by given buyer to identify/estimate the model. We limit to cases (≈ 28,000) where
  - buyers purchase products that are within first six months of release
  - buyers wait at least 3 months between purchases

- Ratings: obs where buyer rated twice (1,279 cases); 5-star = “good”

- Prices: use 90th percentile eBay prices for phones/tablets in first six months of release

- Marginal costs: collected separately from industry sources (tear-down cost reports)
Dynamic, Single-Agent Problem
with endogenously varying unobserved state ($\pi$)

- Consumers choose among 5 products: phone or tablet from Apple or Samsung + outside option

- Given prior $\pi$, consumer $i$ solves

\[
U(\pi, \varepsilon_i) = \max_k \{ v_k(\pi) + \varepsilon_{ki} \}
\]

- $\varepsilon_i \sim$ i.i.d. EV-I with scale parameter $\tau$ captures pref shocks/eBay price discounts

- Choice-specific value function is

\[
v_k(\pi) = \left[ X_k^H + \delta E[U(\pi'(k, H, \pi), \varepsilon')] \right] \gamma_k(\pi)
+ \left[ X_k^L + \delta E[U(\pi'(k, L, \pi), \varepsilon')] \right] [1 - \gamma_k(\pi)] - p_k
\]

where $\gamma_k(\pi) = \alpha_k \pi^f(k) + \beta_k [1 - \pi^f(k)]$ is prob of good outcome
Some Notes on Empirical Model

- We have dynamic discrete choice model where the only state variable is an endogenously varying unobserved state ($\pi_0$ initially, and then updated according to Bayes’ Rule)
- $\pi$ is two-dimensional (one prior for Apple, one for Samsung); treated as independent types

Steps

1. Estimate parameters governing how state evolves ($\alpha_k$ for each product $k$. Constrain $\beta_k = 1 - \alpha_k$)

2. Estimate other parameters via MPEC:
   - $(X^H_k, X^L_k)$: utilities for each product $k$
   - $\tau$: scale of $\varepsilon_i$ shock
   - $\eta$: distributional parameters for density $g(\pi_0; \eta)$

\Rightarrow density of initial state (i.e. initial prior) across consumers.
   Specified as $Beta$ distribution for each firm (2 par. per firm)
First Step: Estimating Informativeness ($\alpha_k$)

- Little-known fact: eBay records consumers’ *product* ratings—like Amazon, but more sparse
  - 28,000 cases where buyers purchase twice
  - only 1,279 where they *rate* twice

- To simplify identification/estimation
  - use this subsample as though representative
  - also constrain $\beta_k = 1 - \alpha_k$ with $\alpha_k > \beta_k$

- Can identify/estimate $\alpha_k$ by

$$\hat{Pr}(H, L)_k + \hat{Pr}(L, H)_k = 2\alpha_k(1 - \alpha_k)$$

(prob of good outcome followed by bad for product $k$ and vice-versa)
Second Step: MPEC

Maximize likelihood of consumer choosing product $k$, then $j$:

$$
\int_0^1 \left\{ \left( \frac{e^{v_j(\Pi_{Hk}(\pi_0))}/\tau}{\sum_l e^{v_l(\Pi_{Hk}(\pi_0))}/\tau} \right) \gamma_k(\pi_0) + \left( \frac{e^{v_j(\Pi_{Lk}(\pi_0))}/\tau}{\sum_l e^{v_l(\Pi_{Lk}(\pi_0))}/\tau} \right) \right\} [1 - \gamma_k(\pi_0)]
$$

$$\times \frac{e^{v_k(\pi_0)}/\tau}{\sum_l e^{v_l(\pi_0)}/\tau} g(\pi_0; \eta) d\pi_0$$

subject to choice-specific value function holding on grid for $\pi_0$:

$$v_j(\pi_0) = \left\{ X_{Hj} + \delta \ln \left( \sum_k e^{v_k(\Pi_{Hj}(\pi_0))} \right) \right\} \gamma_j(\pi_0)$$

$$+ \left\{ X_{Lj} + \delta \ln \left( \sum_k e^{v_L(\Pi_{Lj}(\pi_0))} \right) \right\} [1 - \gamma_j(\pi_0)] - p_j,$$

Parameters: $(X^H_k, X^L_k)$ (utilities), $\tau$ (scale of $\varepsilon_i$), and $\eta$ (distributional parameters for density $g(\pi_0; \eta)$ specified as Beta distribution for both firms)

And $\alpha_j$ enters $\gamma_j$, $\Pi_{Lj}$, and $\Pi_{Jj}$. 
Preference and Information Estimates

<table>
<thead>
<tr>
<th></th>
<th>$X_L$</th>
<th>$X_H$</th>
<th>price</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple phone</td>
<td>67</td>
<td>1,000</td>
<td>640</td>
<td>0.9882</td>
</tr>
<tr>
<td>Apple tablet</td>
<td>-101</td>
<td>1,021</td>
<td>560</td>
<td>0.9677</td>
</tr>
<tr>
<td>Samsung phone</td>
<td>-444</td>
<td>550</td>
<td>400</td>
<td>0.9802</td>
</tr>
<tr>
<td>Samsung tablet</td>
<td>-751</td>
<td>340</td>
<td>340</td>
<td>0.9977</td>
</tr>
</tbody>
</table>

- Units for $X$’s are $/year (relative to outside good utility)
- Great variability in utility realizations
  \Rightarrow incentive to acquire information even if costly
- Each product highly informative ($\alpha$’s far from 0.5)
Potential for Interesting (Weird?) Samsung Tablet Results

Samsung recalls Galaxy Note 7 after battery explosions and fires

The Washington Post

September 2, 2016 at 11:01 a.m. PDT

Samsung recalled all of its new Galaxy Note 7 devices in 10 countries, including the United States, after finding some of the batteries caught on fire or exploded, the company announced Friday.

- What in data leads to low $X_H$?
  - Samsung tablet not purchased much
  - although relatively inexpensive
  - still investigating this
Density of Samsung and Apple Priors

- Initial priors relatively dispersed
- Apple density more skewed
- Suggests few “Apple person” consumers on eBay
Counterfactual Results: Consumer Surplus

Higher under *price discrimination* for most priors; lower at priors close to (0, 1) or (1, 0)
Counterfactual Results: Prices

Lower under *price discrimination* for most priors; higher at priors close to (0, 1) or (1, 0)
Counterfactual Results: Profits (Apple and Samsung)
Lower under *price discrimination* for most priors; higher at priors close to $(0,1)$ or $(1,0)$
Counterfactual Results: Total Welfare
Higher under *price discrimination* for most priors (but not by much)
### Counterfactual Results: Averaging Over Priors
Table shows the change when moving from uniform prices to personalized prices

<table>
<thead>
<tr>
<th>Change ($ per consumer per year)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer surplus</td>
<td>108.30</td>
</tr>
<tr>
<td>Prices paid</td>
<td>-41.79</td>
</tr>
<tr>
<td>Apple profit</td>
<td>-83.19</td>
</tr>
<tr>
<td>Samsung profit</td>
<td>-24.99</td>
</tr>
<tr>
<td>Total profit</td>
<td>-108.18</td>
</tr>
<tr>
<td>Total welfare</td>
<td>0.12</td>
</tr>
</tbody>
</table>

- Units are dollars per consumer per year averaged over priors
- Increase in consumer surplus: tiny increase in total welfare
- Decrease in profits (larger for Apple)
Conclusion

• Analyzed market in which Big Data can be used for pricing
  ◦ currently limited price discrimination used
  ◦ in future, may move closer to perfect personalized pricing

• Characterized pricing and efficiency
  ◦ firms have strategic incentive to manipulate info consumers receive
  ◦ can potentially lead to inefficiency

• Estimates suggest increased ability to discriminate may be *beneficial* to consumers
  ◦ more intense competition for consumers with less extreme tastes
  ◦ efficiency does not decrease
  ⇒ Pricing based on personal data not to be feared if sufficient competition and sufficiently symmetric firm access to information?
  ⇒ Guidance for regulators/consumer protection policies?
Thank you
An Example with Underprovision of Information
Consider duopoly with 2 A products, 1 B product

- A2 perfectly informative (prior jumps to 0 or 1); B uninformative
- Planner chooses more informative variety (A2), but A instead offers A1 in equilibrium (keeps consumer with A)
An Example with *Overprovision* of Information

Consider duopoly with 2 $A$ products, 1 $B$ product

- $A2$ perfectly informative again; $B$ less informative
- Planner chooses *less* informative variety than $A$ (who puts zero weight on bad outcome because it leads to $B$)
A Note on Interpreting Prices

- Not a model of eBay sellers; only using this data to estimate demand parameters (e.g., $X^H_j$, $X^L_j$)
- $p_j$ represents firm’s price for product $j$ (manufacturer’s price), not the price faced on eBay
- Why?
  - difficult to identify choice set of a given consumer on eBay
  - we see what the consumer bought, not specific other listings she considered

- Our trick:
  Think of the $\varepsilon_{ji} \sim$ i.i.d. EV-I, as capturing eBay price discount for product $j$, consumer $i$
A Note on $\delta$ in Dynamic Discrete Demand Estimation

• As in any structural discrete demand model, need to think about outside option purchase
• We see purchases of non-Apple/Samsung phones/tablets $\Rightarrow$ call this outside option
• In data, time between purchases varies across buyers
• We model households as facing a Poisson arrival rate $\lambda$ of purchase need
• In data, we observe mean time between purchases $\Rightarrow$ identifies $\lambda$ (estimated in a first step)
• Let $\delta$ be time discount factor
• Can show that correct adjusted discount factor is $\tilde{\delta} = \frac{\delta}{1-(1-\lambda)\delta}$
Brand Switching Decreases With Purchase History

- Doesn’t immediately jump to 1; consumers still experimenting
- Consistent with consumers learning tastes: more they buy/learn, the less they switch