Manipulative consumers

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July 2024

Research question

- Sellers use consumer data for pricing (and product design)
- Consumers can manipulate their records at a cost

How much is data worth to the seller?

Consumer data

- Data is all the records the seller has about individual consumers
  - demographics
  - past history
  - other things like social network activity, etc.

- Tabulated
  - columns are variables (or attributes)
  - table is infinitelly tall (assume finite sample issues away)
- Variable is a “container”
  - Its informational content is endogenous
  - Determined by a cost of manipulation

Main points

- Price dispersion measures the value of data
  - Data allows the seller to offer different prices to different consumers
  - Price dispersion is a simple measure that aggregates this ability
- “Richer” data (more covariates) is worth less
  - More covariates usually mean better predictive power, but...
  - ...it also makes it easier for the consumers to do arbitrage.

General Data Protection Regulation

Personal data shall be:

(a) processed lawfully, fairly and in a transparent manner in relation to the data subject (‘lawfulness, fairness and transparency’);

...

(c) adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed (‘data minimisation’);

California Consumer Privacy Act

(a) A business that controls the collection of a consumer's personal information shall, at or before the point of collection, inform consumers of the following:
(1) The categories of personal information to be collected and the purposes for which the categories of personal information are collected or used and whether that information is sold or shared.
...

(c) A business' collection, use, retention, and sharing of a consumer's personal information shall be reasonably necessary and proportionate to achieve the purposes for which the personal information was collected or processed ...

Related works

Manipulable data:

- Ball (2021), Frankel and Kartik (2019, 2022) - inference from manipulable data
- Eliaz and Spiegler (2021), Caner and Eliaz (2021) - IC estimators
- Deneckere and Severinov (2017), Severinov and Tam (2019), Perez-Richet and Skreta (2022), Dana, Larsen and Moshary (2023), Tan (2023), Moreno de Barreda and Safonov (2023) - m./test design
- Bonatti and Cisternas (2019), Bhaskar and Roketskiy (2021) - consumer history and price discrimination

Market segmentation:

- Hidir and Vellodi (2020) - IC market segmentation
- Liang and Madsen (2021) - profiling and incentivizing effort
- Eilat, Eliaz and Mu (2020) - restricting informativeness of a price discrimination

Value of data/Privacy:

- Dubé and Misra (2021) - value of personalized pricing
- Bergemann and Bonatti (2015), Bergemann, Bonatti and Smolin (2018) Segura-Rodriguez (2019) - data brokers
- Bonatti, Huang and Villas-Boas (2023)

Consumers

- Continuum of consumers, $C = [0, 1]$
- Willingness to pay for quality $\tau : C \to \{t_\ell, t_h\}$
- Surplus from a transaction with the monopolist: $s(i, q) = \tau(i)q - \frac{q^2}{2}$,
- Premium for quality: $d = t_h - t_\ell$

Monopolistic seller

- produces a variety of vertically differentiated products, quality q (at “zero” cost)
- menu pricing $p(q)$
- can condition the menu on observables $\alpha(i)$
- no commitment to the data practices, use all the data that is available

Consumer data

- $\omega : C \to \{0,1\}^K$ - consumer attributes (ex ante, exogenous, private)
- $\alpha : C \to \{0,1\}^K$ - consumer data (ex post, endogenous, public)
- $\alpha(i)$ is chosen at a cost $\frac{\|\alpha(i)-\omega(i)\|}{K}c$
- $\tau(i)$ is correllated with $\omega(i)$
- $m(\cdot)$ is measure of ℓ-consumers
- $n(\cdot)$ is measure of h-consumers
- two assumptions (A1, A2) on these measures

A1 and A2, preliminary

(A1) A balanced proportion of consumers with low and high willingness to pay for quality.

(A2) Each of the K dimensions of consumer data represent new, cond. independent information (no duplication).

Market segments

- Seller uses consumer data to price the products: a consumer faces prices that depend on her attributes.
- A combo of 2nd and 3rd degree price discrimination:
  - Each market segment $S \in \mathfrak{S}$ gets its own optimal menu.
  - Firm estimates the consumer demand within the segment.
- Market segment labels $\mathfrak{S}$
- Firm regresses attributes to market segments:

$$R : \mathfrak{A} \to \mathfrak{S}$$

Optimal menu in segment S

Demand statistics:

$$h(S) = \frac{n}{m}(\{i \in C : R(\alpha(i)) = S\})$$

Consumer surplus (per H-consumer):

$$U_h(S) = \text{max}\{0, 2d(t_\ell - h(S)d)\}$$

Profit (per ℓ-consumer in S):

$$\rho(S) = h(S)(t_\ell + d)^2 + [\text{max}\{0, t_\ell - h(S)d\}]^2$$

A1

$$\bar{h} \in \left[\frac{c}{2d^2}, \frac{t_\ell}{d} - \frac{c}{2d^2}\right].$$

Value of consumer data

Aggregating profit across segments

Proposition:

$$\pi(S) - \pi^* = d^2 \sum_{\mathbf{a}} \underbrace{m(\mathbf{a}) \left[h(R(\mathbf{a})) - \bar{h}\right]^2}_{\text{Var}\left[h(R(\cdot))\right]} = \frac{1}{4} \sum_{\mathbf{a}} m(\mathbf{a}) \left[p_h(R(\mathbf{a})) - \bar{p}_h\right]^2$$

Corollary: $h(R(\mathbf{a}))$ is a mean-preserving contraction of $h(\mathbf{a})$ hence it is optimal to use all available information

$$R^*(\mathbf{a}) = \mathbf{a}$$

Value = explained variation

- Seller does a non-parametric regression of h on $\mathbf{a}$.
- Part of variation in "premium" demand explained by the data:

$$\sum_{\mathbf{a}} m(\mathbf{a}) \left[h(\mathbf{a}) - \bar{h}\right]^2$$

is the value of consumer data for the seller.

Attributes

Each consumer is endowed with a vector of K binary attributes (personal data):

$$\omega(i) \in \{0,1\}^K$$

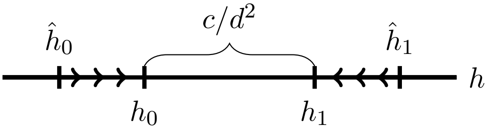
Consumer can change the values of any attributes at a cost. If consumer i sets her attributes to $\alpha(i) \in \{0,1\}^K$ she pays

$$\frac{\|\alpha(i) - \omega(i)\|}{K} c.$$

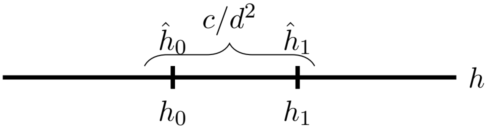
Consumers manipulate their attributes privately before they see the prices.

Incentives to manipulate data, "no-arbitrage constraints"

mixed strategy



no changes to attributes



For any $\mathbf{a}, \mathbf{b} \in \{0,1\}^K$:

$$|h(\mathbf{a}) - h(\mathbf{b})| \leq \frac{c}{d^2} \frac{||\mathbf{a} - \mathbf{b}||}{K}$$

Value of consumer data

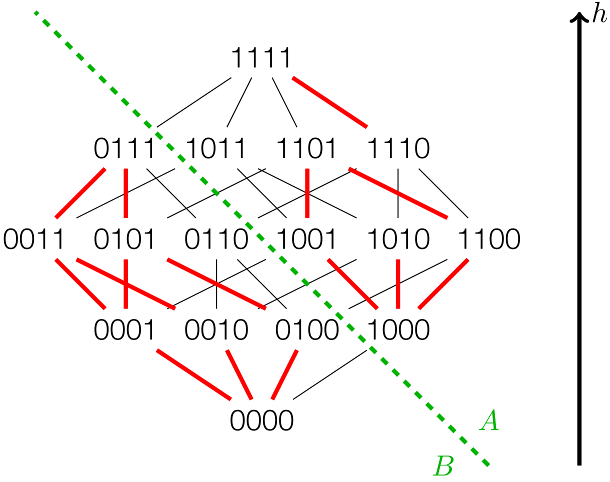
- Value depends on correlation between data and type
- Observed data depends on consumer attributes
- We look at the **seller's best-case scenario:**

$$\max_{h(\cdot)} \sum_{\mathbf{a}} m(\mathbf{a})[h(\mathbf{a}) - \bar{h}]^2$$

$$s.t. \sum_{\mathbf{a}} m(\mathbf{a})[h(\mathbf{a}) - \bar{h}] = 0$$

$$|h(\mathbf{a}) - h(\mathbf{b})| \leq \frac{c}{d^2} \frac{||\mathbf{a} - \mathbf{b}||}{K}, \text{ for all } \mathbf{a}, \mathbf{b} \in \{0,1\}^K$$

Binding constraints



$$\sum_{\mathbf{a}} m(\mathbf{a})[h(\mathbf{a}) - \bar{h}]^2 =$$

$$\sum_{\mathbf{a}\in A} m(\mathbf{a})[h(\mathbf{a}) - h_A]^2 +$$

$$\sum_{\mathbf{a}\in B} m(\mathbf{a})[h(\mathbf{a}) - h_B]^2 +$$

$$m(A)[h(A) - \bar{h}]^2 +$$

$$m(B)[h(B) - \bar{h}]^2$$

Lemma The graph of binding constraints is connected.

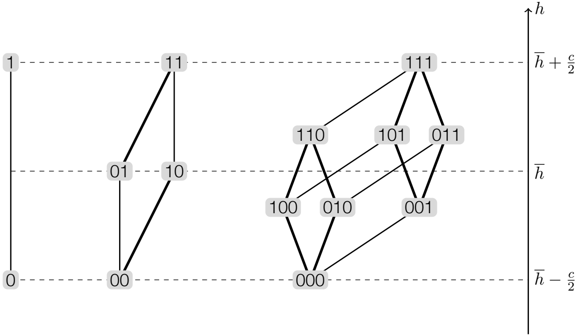
New attributes, new information

A2
There exist marginal probabilities $\mu_i : \{0,1\} \to \mathbb{R}_+, i = 1, .., K$, such that for any vector of attributes $\mathbf{a}$:

$$m(\mathbf{a}) = \bar{m} \prod_{i=1}^{K} \mu_i(\mathbf{a}_i)$$

.

With A2 we can use induction



The main result

If A1 and A2, then the value of consumer data is

$$D = \frac{1}{K}\bar{m}\left[\frac{c}{2d}\right]^2 \frac{\sum_{j=1}^{K} \mu_j(0)\mu_j(1)}{K}$$

Scope for manipulation

The spread of ℓ-consumers across attribute values:

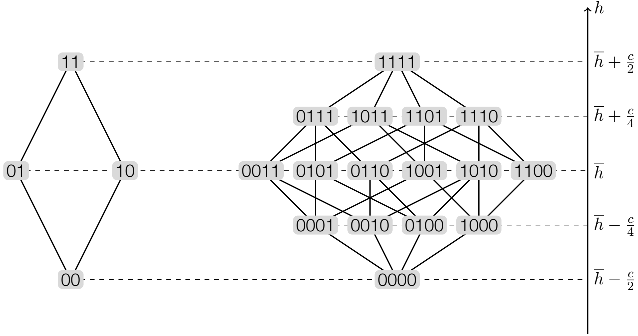
$$\frac{\sum_{j=1}^{K} \mu_j(0)\mu_j(1)}{K}$$

If ℓ-consumers are concentrated, it is easy for the h-consumers to blend in.

The effect of increasing K

$$\frac{1}{K}\bar{m}\left[\frac{c}{2d}\right]^2$$

$$\lim_{K\to\infty}\frac{1}{2^K}\binom{K}{K/2}=1$$



Opaque use of data

As in Frankel and Kartik (2019, 2022) and Ball (2021):

If firm can **commit** to using single **unspecified** attribute then the value of consumer data is

$$D' = \bar{m}\left[\frac{c}{2d}\frac{\sum_{j=1}^{K}\sqrt{\mu_j(0)\mu_j(1)}}{K}\right]^2$$

- For manipulation to be fruitful, consumers need to guess which attribute to manipulate
- The seller uses attribute j with prob. $\frac{\sqrt{\mu_j(0)\mu_j(1)}}{\sum_{k=1}^{K}\sqrt{\mu_k(0)\mu_k(1)}} \approx \frac{1}{K}$.
- This reduces the gain from manipulation by a factor of $\frac{1}{K}$.

Conclusion

- Value of information is measured by the price variance
- Adding new (non-duplicating) variables to the data, increases both informational content and manipulation opportunities–the latter erodes value