The Value of Data Records

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Motivation

Personal data is a key input in the modern economy

- Search and social media platforms use it to sell targeted ads
- E-commerce platforms use it to intermediate buyers and sellers
- Matching platforms use it decrease search frictions

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This Paper: How much of this value is generated by the data of a single individual?

This question is at the core of some recent debates on data markets:

- Compensate individuals for their data (Seim et al., '22, PW'18)
- Conduct demand analysis in data markets (FTC '14)
- Data as a source of market power (Stiegler Report '19)

example

A Simple Example

A two-sided market:

- An e-commerce platform
- Many buyers
- A firm (third-party seller)

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6 million such records

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– ω_H reveals buyer has valuation 2	6 million such records

Seller knows database composition but ignores each specific ω

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Platform is an **intermediary** that provides the firm with **information** about each buyer, and thus can influence the price it charges to them

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Question: How much value does platform derive from each record?

A Simple Example

An optimal information policy for the platform: (as in BBM '15, *AER*)

Record of type $\omega_L \longrightarrow s^L$

Record of type $\omega_H \xrightarrow{\frac{1}{2}} s^L$

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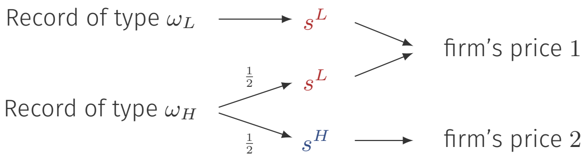

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$$\begin{tikzcd}
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& & \text{firm's price } 1 \\
& s^L \arrow[ur] & \\
\text{Record of type } \omega_H \arrow[ur, "\frac{1}{2}"] \arrow[dr, "\frac{1}{2}"'] & & \\
& s^H \arrow[r] & \text{firm's price } 2
\end{tikzcd}$$

Thus, platform's **payoff** is $u^*(\omega) = \begin{cases} 0 & \text{if } \omega_L \\ \frac{1}{2} & \text{if } \omega_H \end{cases}$

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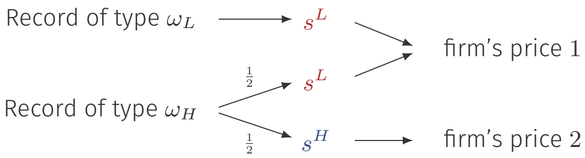

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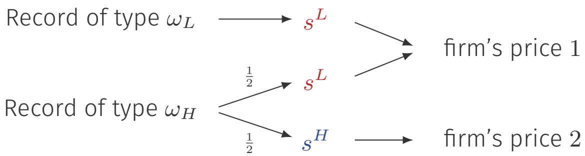

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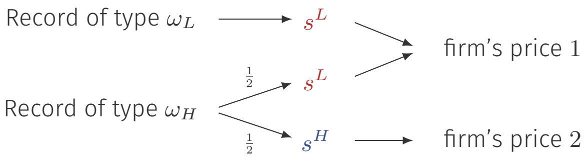

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1. Most valuable records are those yielding lowest payoff
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\begin{tikzcd}
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\text{Record of type } \omega_H \arrow[ur, "\frac{1}{2}"] \arrow[dr, "\frac{1}{2}"'] & & \\
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Approach. Platform uses inputs (data records) to produce outputs (information). We use LP **duality** to characterize the **values** of these inputs

(Dorfman et al. '87 and Gale '89)

Literature

This paper connects two fast-growing literatures:

1. Data Markets — Bergemann and Bonatti (2019) Bergemann and Ottaviani (2021)

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     - Ann’s record uninformative about Bob’s $\rightsquigarrow$ new data externality
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   - See paper for connections to mecha/info design and duality

Plan for Rest of the Talk

1. Model
2. Values of Data Records & their externalities
3. Characterize Preferences over Databases

model

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A **buyer's** preference pinned down by independently distributed θ

A buyer's record is of type $\omega \in \Omega$ and is (partially) informative about her θ

Database composition $q \in \mathbb{R}_+^\Omega$ is common knowledge

For $i \in \{0, 1\}$, $u_i : A \times \Omega \to \mathbb{R}$ denotes i's **expected** payoff function

Platform intermediates the interaction between the firm and the buyers

Specifically, platform acts as an **information designer**:

- It sends the firm information about each record ω so as to influence the firm's action a (price, discount, features, ect.)

Remark. WLOG to focus on "recommendation" mechanisms like

$$x : \Omega \to \Delta(A)$$

The platform's problem is then: as in Bergemann-Morris '16

$$\mathcal{U}_q: \qquad \max_x \sum_{\omega,a} u_0(a,\omega)x(a|\omega)q(\omega)$$

s.t. for all a, a',

$$\sum_{\omega} \Big(u_1(a,\omega) - u_1(a',\omega)\Big)x(a|\omega)q(\omega) \geq 0$$

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We let x_q^* be an optimal solution and define

- **direct payoff** of type-ω record: $u_q^*(\omega) \triangleq \sum_a u_0(a, \omega) x_q^*(a|\omega)$
- **total payoff** of database: $U^*(q) \triangleq \sum_\omega u_q^*(\omega) q(\omega)$

Today's results immediately extend to more general settings

- Multiple agents: E.g., competing firms
- Platform does more than information: E.g., allocations and transfers
- Agents have some of the principal's data

values of data records

Platform uses records as inputs to produce output in the form of informative recommendations $\rightsquigarrow$ linear program $\mathcal{U}_q$

We use duality to reveal value of each input Dorfman et al. '87, Gale '89

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Let $v : \Omega \to \mathbb{R}$ and $\lambda : A \times A \to \mathbb{R}_+$

The Data-Value Problem:

$$\mathcal{V}_q : \qquad \min_{\lambda, v} \sum_{\omega} v(\omega) q(\omega)$$

s.t. for all $\omega \in \Omega$,

$$v(\omega) = \max_{a \in A} \Big\{ u_0(a,\omega) + t(a,\omega) \Big\} \qquad \text{(value formula)}$$

where $t(a,\omega) \triangleq \sum_{a' \in A} \Big(u_1(a,\omega) - u_1(a',\omega) \Big) \lambda(a'|a)$

Lemma 1 (Duality)

$\mathcal{V}_q$ is equivalent to the dual of $\mathcal{U}_q$. For every optimal solution v_q^* and x_q^*,

$$\sum_{\omega \in \Omega} v_q^*(\omega) q(\omega) = U^*(q) \triangleq \sum_{\omega \in \Omega} u_q^*(\omega) q(\omega)$$

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- $v_q^*(\omega)$ is multiplier of feasibility constraint $\rightsquigarrow$ captures the effect on $U^*(q)$ of a change in $q(\omega)$
- $v_q^*(\omega)$ is the **unit value** of a record of type ω (Gale '89)
- We characterize the properties of $v_q^*(\omega)$

Decomposing the Value of a Record

What determines the value of a record?

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Proposition (Decomposition)

The value of a record ω can be decomposed as

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$$u_q^*(\omega) \triangleq \sum_a u_0(a,\omega) x_q^*(a|\omega) \qquad \text{direct payoff}$$

- $u_q^*(\omega)$ captures the payoff that platform earns directly from record

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$$t_q^*(\omega) \triangleq \sum_a t^*(a,\omega) x^*(a|\omega) \overset{\text{a.e.}}{=} \sum_{\omega'} q(\omega') \frac{\partial}{\partial q(\omega)} u_q^*(\omega') \qquad \textbf{externality}$$

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- Externality relates to seller's **incentives** to disobey recommendations

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- $t_q^*(\omega)$ **externality** that ω exerts on payoffs generated by other records
- This result clarifies why/when $u_q^*(\omega)$ is biased measure of value

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Recall notation:

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Corollary

$$\text{If} \quad u_q^*(\omega) < \bar{u}(\omega), \quad \text{then} \quad t_q^*(\omega) > 0$$

Idea:

- $u_q^*(\omega) < \bar{u}(\omega)$ implies platforms withhold some information from firm

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$$\begin{array}{llll} \text{If} & u_q^*(\omega) < \bar{u}(\omega), & \text{then} & t_q^*(\omega) > 0 \\ \text{If} & t_q^*(\omega) < 0, & \text{then} & u_q^*(\omega) > \bar{u}(\omega) \end{array}$$

Moreover, $t_q^*(\omega) < 0$ for some ω if and only if $t_q^*(\omega') > 0$ for some ω'

Idea:

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Takeaways

- This externality arises when platform **withholds info** from firms by pooling data records
    - Intermediation problems, as opposed to decision problems
        - Intermediation may involve balancing conflicting interests
    - Ubiquitous due to rise of "info-mediaries" Acquisti et al. (16)

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    - Intermediation problems, as opposed to decision problems
        - Intermediation may involve balancing conflicting interests
    - Ubiquitous due to rise of "info-mediaries" Acquisti et al. (16)
- The externality arises even when records are statistically **independent**
    - Thus, unrelated to "learning" externalities, (vs Choi et al. (19), Bergemann et al. (20), Acemoglu et al. (21), Ichihashi (21))

demand for data

Having More Data

What is the platform's **willingness to pay** for more data?

We study two cases ($\approx$ kinds of information products):

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We can study both cases by exploring how v_q^* depends on q

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Platform as a "consumer" of data records:

- $U^*(q)$ is (indirect) utility of a bundle q (i.e. the database)

Therefore,

- WTP for type-ω records is revealed by marginal utility: $v_q^*(\omega)$
- Substitutability between records: $MRS_q(\omega, \omega') \stackrel{\text{a.e.}}{=} -\frac{v_q^*(\omega)}{v_q^*(\omega')}$

Thus, v_q^* characterizes the platform's preferences over databases

Use this to characterize properties of the demand function

How does $v_q^*(\omega)$ depend on $q(\omega)$?

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Notation: $\mu_q(\omega) \triangleq \dfrac{q(\omega)}{\sum_{\omega'} q(\omega')}$ is the frequency of type-ω records

Proposition (Scarcity Principle)

Fix q and q'. If $\mu_q(\omega) < \mu_{q'}(\omega)$, then $v_q^*(\omega) \geq v_{q'}^*(\omega)$.

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Moreover, when $\mu_q(\omega)$ grows, $v_q^*(\omega) \searrow \bar{u}(\omega) \triangleq$ payoff under full-disclosure

Example (continued): Demand Curve

An example of a **demand curve** for records of type ω_K

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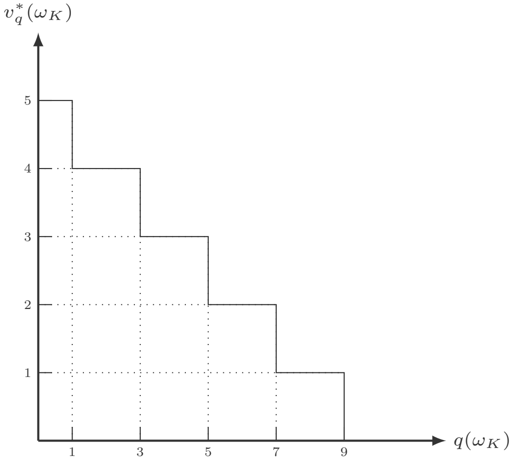

Setting $\beta = 0$, $K = 10$, $q(\omega_k) = 1\ \forall k < K$

Complement or Substitutes

Are different types of data records complements or substitutes?

Result. Data records exhibit complementaries iff platform withholds some information

Let’s first see this through an example

Example (continued): Indifference Curves

Recall that: $u_0(a, \omega) = \beta\Big(\text{seller's profit}\Big) + (1-\beta)\Big(\text{buyer's surplus}\Big)$

An example of the platform's **indifference curves**

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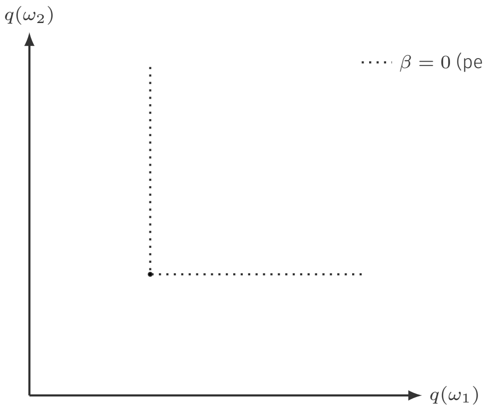

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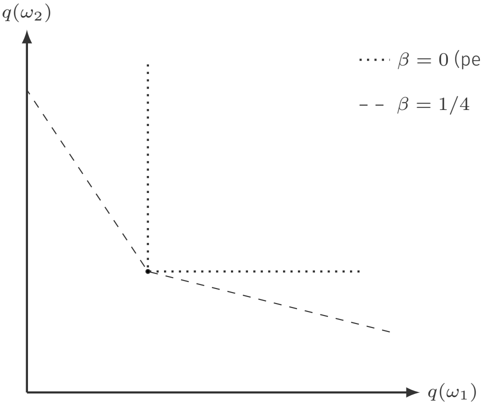

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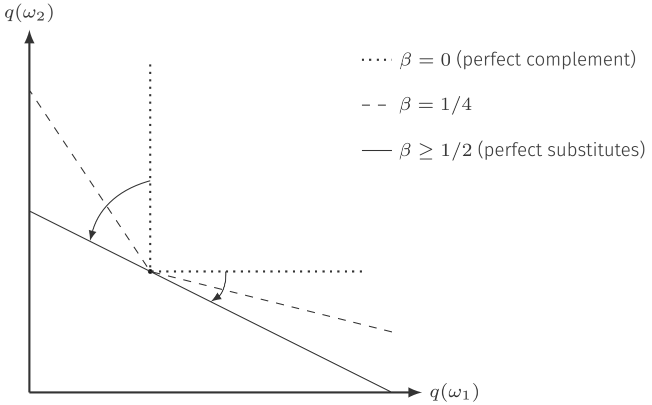

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Are Records Complement or Substitutes?

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Proposition

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Having More Data

What is the platform's WTP for more data?

The colloquial "*having more data*" can indicate two different things:

1. The platform obtains *more* records
2. The platform obtains *better* records

We can study both problems by exploring how $v_q^*(\omega)$ depends on q

Refining Existing Records

Records are often only partially informative about θ and platform can **learn** more about them $\rightsquigarrow$ we call this "**refining**" a record

Questions:

- How do refinements change the value derived from *each* record?
- Do refinements benefit platform *overall* $\rightsquigarrow$ positive WTP?

A classic question from a new perspective

Definition. (link to formalism)

A refinement refines:

- A share $\alpha \in [0, 1]$ of the existing records of type ω
- Does so according to rule $\sigma_\omega \in \Delta(\Omega)$
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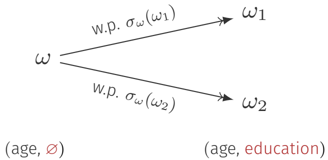

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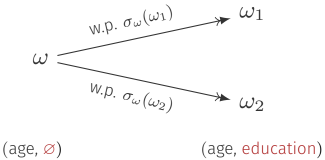

Thus, it transforms the original database $q \rightsquigarrow q_\alpha$ such that:

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Corollary:

Consider refining α-share of type-ω records:

Direct Effects. The value of each *refined* record increases:

$$\sum_{\omega' \in \Omega} v^*_{q_\alpha}(\omega')\sigma_\omega(\omega') \geq v^*_q(\omega)$$

Indirect Effects. The value of *unrefined* records affected too:

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This characterizes some of the possible externalities when disclosing personal data

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- Marginally **decreasing** in α

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conclusions

Summary

We show how to compute the **unit value** of a buyer's specific data record

- Uncover novel data **externalities**, specific to **intermediation** problems

  Due to pooling records to withhold information

- Direct payoff gives a biased account of the value of a record

Use our theory to characterize basic properties of the demand for data:

- *"More"* records: demand for records, complements vs substitutes
- *"Better"* records: mixed effects on unit values, overall WTP

Overall, an investigation of the **demand side** of data markets

Next Steps: Privacy

Work in progress: how protecting privacy affects the value of data

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In a richer model:

- Each buyer as an agent and ω as her **private** data
- Buyer can agree to disclose ω to platform if she wants
- Thus, platform has to elicit such data in order to use it

Use + Elicitation = LP problem $\rightsquigarrow$ Same approach as in this paper

Preliminary findings:

- Privacy decreases total value of the database (of course!)
- But it can **increase** the value of some records (redistributive effects)

appendix

How does v_q^* depend on q?

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v_q^* goes beyond a *marginal* interpretation $\rightsquigarrow$ WTP for discrete changes in q

Proposition (Stability)

There exists finite collection $\{Q_1, \ldots, Q_K\}$ of open sets in $\mathbb{R}_+^\Omega$ s.t.:

- $\bigcup Q_k$ has full measure
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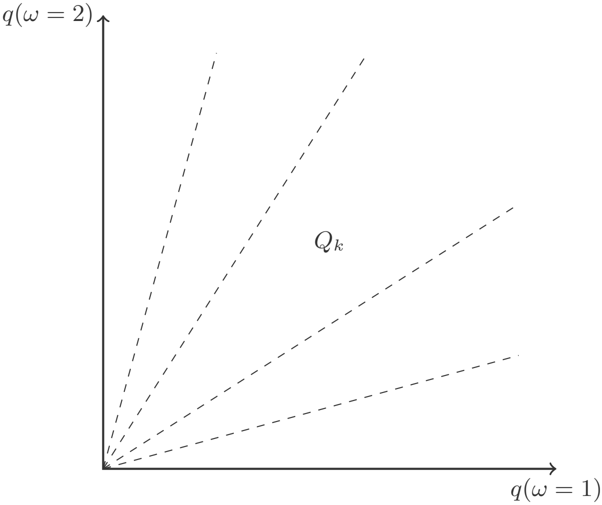
Note : v_q^* constant in Q_k even though x_q^* changes

Proof idea : algebraic representation of extreme points & optimality


$q(\omega = 2)$
Q_k
$q(\omega = 1)$

Proposition

For $\beta \leq \frac{1}{2}$,

$$v_q^*(\omega) = \begin{cases} (1-\beta)\omega & \text{if } \omega < a_q \\ \beta a_q + (1-\beta)(\omega - a_q) & \text{if } \omega \geq a_q; \end{cases}$$

Moreover, $t_q^*(\omega) > 0$ for $\omega < a_q$ and $t_q^*(\omega) \leq 0$ for $\omega \geq a_q$

For $\beta \geq \frac{1}{2}$ we have $v_q^*(\omega) = u_q^*(\omega) = \beta\omega$ for all ω

Formalizing Refinements

Let $p_\omega \in \Delta(\Theta)$ be belief about buyer's θ if her record is of type ω

A **refinement** is $\sigma_\omega \in \Delta(\Omega)$ s.t. $\sum_{\omega' \in \Omega} \sigma_\omega(\omega') p_{\omega'} = p_\omega$

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