The Value of Data Records

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Motivation

Personal data has become 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

In each case, personal data fuels a multi-billion dollars industry

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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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- ω_L reveals buyer has valuation 1
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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

Firm chooses prices to maximizes profits (MC = 0)

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Suppose platform choose information to maximizes buyer's surplus

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 $\omega_L \longrightarrow s^L$

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

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\begin{tikzcd}
\text{Record of type } \omega_L \arrow[r] & s^L \arrow[dr] & \\
& & \text{firm's price } 1 \\
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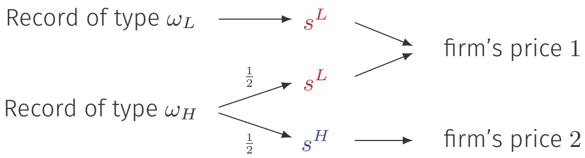

Thus, platform's **payoff** is $u^*(\omega) = \begin{cases} 0 & \text{if } \omega_L \\ \frac{1}{2} & \text{if } \omega_H \end{cases}$

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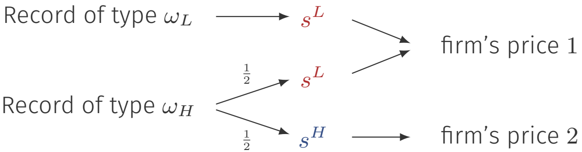

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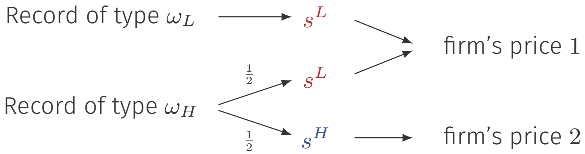

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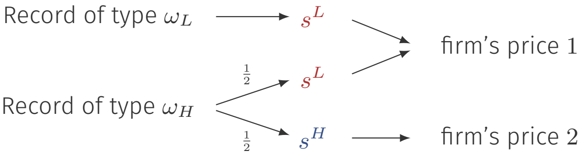

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1. Most valuable records are those yielding lowest payoff
2. ω_L generates no payoff but "helps" ω_H earn positive surplus
3. Payoff u^* gives *biased* account of the value created by a record

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2. What is the platform's WTP for "more data"?

- For *more* data records — Marketing Lists

  E.g., Platform obtains access to *new* buyers

- For *better* data records — Data Appends

  E.g., Platform obtains more characteristics about *existing* buyers

Approach

Formulate the platform's problem as an information-design problem

We interpret it as a physical production problem:

- Platform uses **inputs** (data records) to produce **outputs** (signals/recommendations)

Use LP **duality** to characterize the **unit value** of these inputs in this "production" problem (Dorfman et al. '87 and Gale '89)

Contributions

In this paper:

1. We show how to compute the value of data for an intermediary and study the properties of the demand for data
2. We uncover a new **data externality** that, if ignored, can bias our assessment of the value of data
3. We offer a benchmark for how to compensate consumers for their data

Literature

This paper connects two fast-growing literatures:

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

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2. Information design — Bergemann and Morris (2019), Kamenica (2019)
   - See paper for connections to mecha/info design and duality

Plan for Rest of the Talk

1. Model
2. Value of Data Records & their externalities
3. Properties of the demand for data

model

Model

For the talk, model simply generalizes the example

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Denote **platform** by $i = 0$; denote **firm** by $i = 1$ and his action $a \in A$

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

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Denote **platform** by $i = 0$; denote **firm** by $i = 1$ and his action $a \in A$

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

Model

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

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

Model

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

Why caring about this generality? More applications besides e-commerce: sponsored-search auctions, rideshare, navigation value of data records

Value Problem

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:

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

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

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

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

- $t_q^*(\omega)$ **externality** that ω exerts on payoffs generated by other records

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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

We characterize when records exert positive vs negative externalities

Externality

We characterize when records exert positive vs negative externalities

Recall notation:

- $u_q^*(\omega) \rightsquigarrow$ direct payoff the platform obtains from record
- $\bar{u}(\omega) \rightsquigarrow$ payoff the platform could obtain with "full disclosure"

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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:

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

- 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)

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)
- 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))

Example

Back to our introductory example:

Suppose $\Omega = \{\omega_1, \ldots, \omega_K\}$ and record of type ω_k fully reveals that $\theta = \omega_k$

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Suppose $\Omega = \{\omega_1, \ldots, \omega_K\}$ and record of type ω_k fully reveals that $\theta = \omega_k$

Suppose platform objective is:

$$u_0(a, \omega) = \beta\Big(\underbrace{a\mathbb{1}\{\omega \geq a\}}_{\text{seller's profit}}\Big) + (1-\beta)\Big(\underbrace{\max\{\omega - a, 0\}}_{\text{buyer's surplus}}\Big) \qquad \text{for } \beta \in [0,1]$$

Example

Proposition (Single-Crossing)

If $\beta < 1/2$, then $t_q^*(\omega) > 0$ for all $\omega < a_q$ and $t_q^*(\omega) \leq 0$ for all $\omega \geq a_q$

When β small, u_q^* provides biased account of the value of each record

Ignoring this externality may lead to:

- over-compensate higher-valuation buyers for their data $u_q^*(\omega) > v_q^*(\omega)$
- under-compensate lower-valuation buyers for their data $u_q^*(\omega) < v_q^*(\omega)$

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If $\beta \geq 1/2$, then $t_q^*(\omega) = 0$ for all ω

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When β large, interests are "sufficiently" aligned: externality disappears 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: $MRS_q(\omega, \omega') \overset{\text{a.e.}}{=} -\frac{v_q^*(\omega)}{v_q^*(\omega')}$

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

Use this to characterize properties of the **demand function**

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Proposition (Scarcity Principle)

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

Demand for Records

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

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

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Example (continued): Demand Curve

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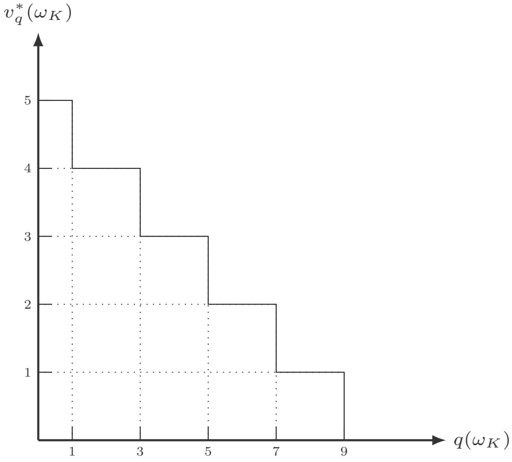

Setting $\beta = 0$, $K = 10$, $q(\omega_k) = 1 \; \forall k < K$

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

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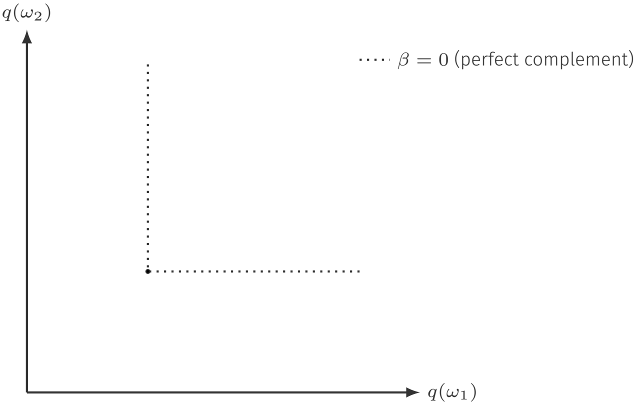

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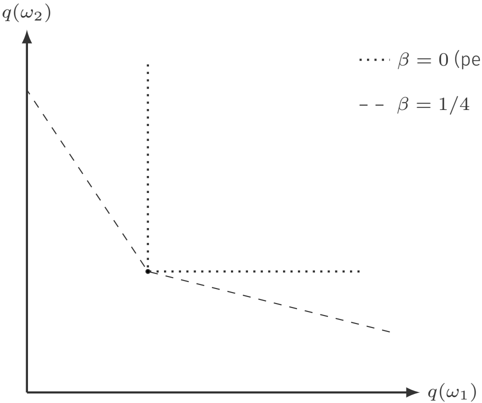

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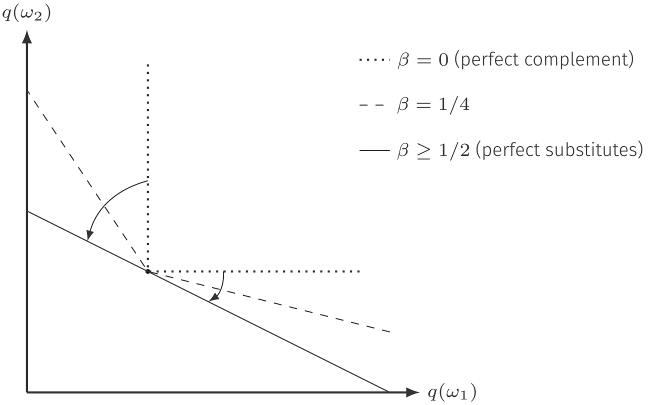

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Having More Data

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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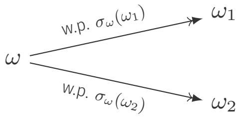

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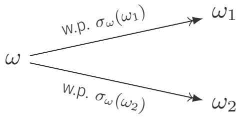

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Thus, it transforms the original database $q \rightsquigarrow q_\alpha$ such that:

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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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WTP for Better Records

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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?

Stability

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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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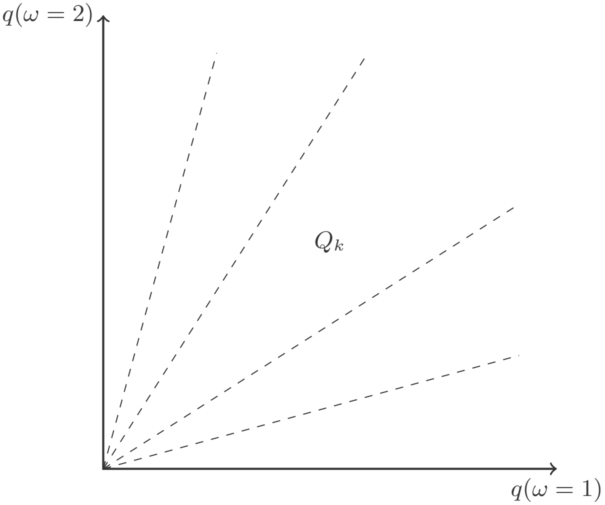
Note : v_q^* constant in Q_k even though x_q^* changes

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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