

Data and Privacy: Tools from Information Design

Jacopo Perego
Columbia University

January 2025

Personal data has become key input of the modern economy

Economics of Data:

- ▶ Implications of collecting, trading, using personal data on economics outcomes, e.g., consumer welfare, market power, etc.
- ▶ Institutions, e.g., data markets, privacy laws, data unions, etc.

Personal data has become key input of the modern economy

Economics of Data:

- ▶ Implications of collecting, trading, using personal data on economics outcomes, e.g., consumer welfare, market power, etc.
- ▶ Institutions, e.g., data markets, privacy laws, data unions, etc.

Spanning fields: micro and macro, theoretical and empirical, field and lab

A space where micro theory can aim to be sophisticated and practically relevant

Personal data has become key input of the modern economy

Economics of Data:

- ▶ Implications of collecting, trading, using personal data on economics outcomes, e.g., consumer welfare, market power, etc.
- ▶ Institutions, e.g., data markets, privacy laws, data unions, etc.

Spanning fields: micro and macro, theoretical and empirical, field and lab

A space where micro theory can aim to be sophisticated and practically relevant

Today ⇒ A Methodological Point

How/why tools from **information design** constitute a building block to study questions concerning the **economics data** (plus some future directions)

model

Model

The typical **Information Design** setting:

- A finite set Ω of payoff states (e.g., demand condition)
- A common prior belief of about ω , denoted $q \in \Delta(\Omega)$
- One “designer,” N agents (e.g., e-com platform and merchants)
- Finite action sets $A_0 \times A_1 \times \dots \times A_N =: A$ (e.g., price, feature, quality)
- Payoffs: $v : A \times \Omega \rightarrow \mathbb{R}$ for the designer; $u_i : A \times \Omega \rightarrow \mathbb{R}$ for each agent

Model

The typical **Information Design** setting:

- A finite set Ω of payoff states (e.g., demand condition)
- A common prior belief of about ω , denoted $q \in \Delta(\Omega)$
- One “designer,” N agents (e.g., e-com platform and merchants)
- Finite action sets $A_0 \times A_1 \times \dots \times A_N =: A$ (e.g., price, feature, quality)
- Payoffs: $v : A \times \Omega \rightarrow \mathbb{R}$ for the designer; $u_i : A \times \Omega \rightarrow \mathbb{R}$ for each agent
- Base Game: $G = (\Omega, q, N, (A_i, u_i)_{i \in N})$

Model

The typical **Information Design** setting:

- A finite set Ω of payoff states (e.g., demand condition)
- A common prior belief of about ω , denoted $q \in \Delta(\Omega)$
- One “designer,” N agents (e.g., e-com platform and merchants)
- Finite action sets $A_0 \times A_1 \times \dots \times A_N =: A$ (e.g., price, feature, quality)
- Payoffs: $v : A \times \Omega \rightarrow \mathbb{R}$ for the designer; $u_i : A \times \Omega \rightarrow \mathbb{R}$ for each agent
- Base Game: $G = (\Omega, q, N, (A_i, u_i)_{i \in N})$
- An information structure is a pair (S, π) s.t. $S = S_1 \times \dots \times S_N$ (finite) and $\pi : \Omega \rightarrow \Delta(S)$

Model

- Base game + information structure: $(G, (S, \pi)) \Rightarrow$ a **Bayesian game**
- Solution concept: BNE

Model

- Base game + information structure: $(G, (S, \pi)) \Rightarrow$ a **Bayesian game**
- Solution concept: BNE

The **information-design** problem:

$$V(q) = \max_{(S, \pi)} \max_{\sigma \in \text{BNE}(G, (S, \pi))} \sum_{\omega, s, a} v(a, \omega) \sigma(a|s) \pi(s|\omega) q(\omega)$$

Applications

- ▶ Online marketplaces:

Platform runs marketplace where buyers and sellers trade goods. It designs algorithm providing info to parties about value of trade

Applications

- ▶ Online marketplaces:

Platform runs marketplace where buyers and sellers trade goods. It designs algorithm providing info to parties about value of trade

- ▶ Ad auctions

Platform runs (fixed-format) auctions to sell impressions. It designs algorithm that allows bidders to condition bid on users' characteristics

Applications

- ▶ Online marketplaces:

Platform runs marketplace where buyers and sellers trade goods. It designs algorithm providing info to parties about value of trade

- ▶ Ad auctions

Platform runs (fixed-format) auctions to sell impressions. It designs algorithm that allows bidders to condition bid on users' characteristics

Limiting assumptions of the standard model:

Commitment power, equilibrium selection, inherently static

Obedient Recommendation Mechanisms

The ID problem can be equivalently formulated as choosing an obedient direct **recommendation mechanism** $x : \Omega \rightarrow \Delta(A)$: Bergemann and Morris '16, *TE*

$$V(q) = \max_{x: \Omega \rightarrow \Delta(A)} \sum_{\omega, a} v(a, \omega) x(a|\omega) q(\omega)$$

such that, for all $i \in N$, $a_i, a'_i \in A_i$

$$\sum_{\omega, a_{-i}} \left(u_i(a_i, a_{-i}, \omega) - u_i(a'_i, a_{-i}, \omega) \right) x(a_i, a_{-i}|\omega) q(\omega) \geq 0$$

Obedient Recommendation Mechanisms

The ID problem can be equivalently formulated as choosing an obedient direct **recommendation mechanism** $x : \Omega \rightarrow \Delta(A)$: Bergemann and Morris '16, *TE*

$$V(q) = \max_{x: \Omega \rightarrow \Delta(A)} \sum_{\omega, a} v(a, \omega) x(a|\omega) q(\omega)$$

such that, for all $i \in N$, $a_i, a'_i \in A_i$

$$\sum_{\omega, a_{-i}} \left(u_i(a_i, a_{-i}, \omega) - u_i(a'_i, a_{-i}, \omega) \right) x(a_i, a_{-i}|\omega) q(\omega) \geq 0$$

A finite-dimensional linear program \Rightarrow Quite tractable

The typical object of interest in the ID literature: Characterize the optimal x

a different perspective

Using a Database

Information Design as the problem of how to “optimally use a **database**”

Using a Database

Information Design as the problem of how to “optimally use a **database**”

Consider a population of consumers, each with unobserved type $\theta \in \Theta$

For each consumer, there is a **data record** of her personal characteristics, which is informative about her θ

Using a Database

Information Design as the problem of how to “optimally use a **database**”

Consider a population of consumers, each with unobserved type $\theta \in \Theta$

For each consumer, there is a **data record** of her personal characteristics, which is informative about her θ

- ▶ It's the realization of an exogenous signal, denoted by ω , which induces a posterior belief about θ
- ▶ $v(a, \omega)$ and $u_i(a, \omega)$ denote the *expected payoffs* conditional on ω

Using a Database

Information Design as the problem of how to “optimally use a **database**”

Consider a population of consumers, each with unobserved type $\theta \in \Theta$

For each consumer, there is a **data record** of her personal characteristics, which is informative about her θ

- ▶ It's the realization of an exogenous signal, denoted by ω , which induces a posterior belief about θ
- ▶ $v(a, \omega)$ and $u_i(a, \omega)$ denote the *expected payoffs* conditional on ω

A **database** of data records: $q = (q(\omega))_{\omega \in \Omega} \in \mathbb{R}_+^\Omega$

Same Problem

$$V(q) = \max_{x: \Omega \rightarrow \Delta(A)} \sum_{\omega, a} v(a, \omega) x(a|\omega) q(\omega)$$

such that, for all $i \in N$, $a_i, a'_i \in A_i$

$$\sum_{\omega, a_{-i}} \left(u_i(a_i, a_{-i}, \omega) - u_i(a'_i, a_{-i}, \omega) \right) x(a_i, a_{-i}|\omega) q(\omega) \geq 0$$

Same Problem

$$V(q) = \max_{x: \Omega \rightarrow \Delta(A)} \sum_{\omega, a} v(a, \omega) x(a|\omega) q(\omega)$$

such that, for all $i \in N$, $a_i, a'_i \in A_i$

$$\sum_{\omega, a_{-i}} \left(u_i(a_i, a_{-i}, \omega) - u_i(a'_i, a_{-i}, \omega) \right) x(a_i, a_{-i}|\omega) q(\omega) \geq 0$$

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Why is this interesting?

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Why is this interesting?

- $V(q)$ microfound the intermediary's preference over databases, which is a key building block of any model of a data economy

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Why is this interesting?

- $V(q)$ microfounds the intermediary's preference over databases, which is a key building block of any model of a data economy
- Importance of the interpretation

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Why is this interesting?

- $V(q)$ microfounds the intermediary's preference over databases, which is a key building block of any model of a data economy
- Importance of the interpretation

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Examples of Questions

from Galperti, Levkun, Perego (2023, *Restud*)

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Examples of Questions

from Galperti, Levkun, Perego (2023, *Restud*)

- What is the value for the intermediary of each single data record in q ?
A benchmark for compensating individuals for their data

New Questions

From this interpretation, several questions arise:

1. Characterize properties of the value function $V : \mathbb{R}_+^\Omega \rightarrow \mathbb{R}$

Examples of Questions

from Galperti, Levkun, Perego (2023, *Restud*)

- What is the value for the intermediary of each single data record in q ?

A benchmark for compensating individuals for their data

- What are the properties of the “demand function” for data

Law of demand — as $q(\omega) \nearrow$, value of ω -records \searrow

Indifference curves — When are records complement/substitute?

Merging databases: When is $V(q + q') > V(q) + V(q')$?

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Why is this interesting?

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Why is this interesting?

- Who supplies the data records in practice? Often, the intermediary needs to obtain the data records from the consumers themselves, by promising a service and/or a financial compensation

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Why is this interesting?

- Who supplies the data records in practice? Often, the intermediary needs to obtain the data records from the consumers themselves, by promising a service and/or a financial compensation
- This leads us to models of “**markets for data**”

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Why is this interesting?

- Who supplies the data records in practice? Often, the intermediary needs to obtain the data records from the consumers themselves, by promising a service and/or a financial compensation
- This leads us to models of “**markets for data**”

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Monopsony: The intermediary has all the bargaining power

Paradigm: Information design with elicitation (obedience + truthtelling constraints)

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Monopsony: The intermediary has all the bargaining power

Paradigm: Information design with elicitation (obedience + truthtelling constraints)

Variations: Cheap talk or verifiable disclosure? Transfers or not?

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Monopsony: The intermediary has all the bargaining power

Paradigm: Information design with elicitation (obedience + truth-telling constraints)

Variations: Cheap talk or verifiable disclosure? Transfers or not?

Galperti and Perego, 2023 (*AEA P&P*) discussed a few examples

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Monopsony: The intermediary has all the bargaining power

Paradigm: Information design with elicitation (obedience + truth-telling constraints)

Variations: Cheap talk or verifiable disclosure? Transfers or not?

Galperti and Perego, 2023 (*AEA P&P*) discussed a few examples

IMHO: Still underexplored framework

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Monopsony: The intermediary has all the bargaining power

Paradigm: Information design with elicitation (obedience + truthtelling constraints)

Variations: Cheap talk or verifiable disclosure? Transfers or not?

Galperti and Perego, 2023 (*AEA P&P*) discussed a few examples

IMHO: Still underexplored framework

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Competitive Markets: Competing intermediaries with no bargaining power

Intermediaries pay consumers for their data records

Competitive price for each type of data record clears the market:

supply of data records = demand

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Competitive Markets: Competing intermediaries with no bargaining power

Intermediaries pay consumers for their data records

Competitive price for each type of data record clears the market:

supply of data records = demand

- Failure of first welfare theorem: Consumers don't internalize how selling their data affects the intermediary's optimal recommendation mechanism

New Questions

From this interpretation, several questions arise:

2. We can make q endogenous

Examples of Markets

Competitive Markets: Competing intermediaries with no bargaining power

Intermediaries pay consumers for their data records

Competitive price for each type of data record clears the market:

supply of data records = demand

- Failure of first welfare theorem: Consumers don't internalize how selling their data affects the intermediary's optimal recommendation mechanism

Galperti, Liu, Perego '24 (For more details on this, come to my talk!)

Sunday @8am, Session title: *Competitive Implications of Data Sharing*

conclusions

Conclusions

- ▶ A large literature in **information design** provides natural framework and powerful tools to study questions concerning the **economics of data**
- ▶ Information design as a production problem:
Input: Personal Data → Output: Optimal Information
- ▶ A new perspective: How does changing inputs affects economic outcomes (through changes in optimal information)?
- ▶ This is key for studying: The value of data; The effects of privacy protection policies; The role of data unions; etc.
- ▶ In my view, a natural direction for the literature: lots of open questions and high demand for better theory

an example

Example: Properties of V

example

A **merchant** sells its product through an e-commerce **platform**

The platform is used by group of **consumers**, each with independent valuation for the product

A **merchant** sells its product through an e-commerce **platform**

The platform is used by group of **consumers**, each with independent valuation for the product

For each consumer, platform exogenously owns a database q of data records

Each data record is informative about the corresponding consumer's valuation for the merchant product

A **merchant** sells its product through an e-commerce **platform**

The platform is used by group of **consumers**, each with independent valuation for the product

For each consumer, platform exogenously owns a database q of data records

Each data record is informative about the corresponding consumer's valuation for the merchant product

Only two **types** of records:

- ω_L reveals consumer has valuation 1
- ω_H reveals consumer has valuation 2

Platform's **database** contains:

- 3 million such records
- 6 million such records

A **merchant** sells its product through an e-commerce **platform**

The platform is used by group of **consumers**, each with independent valuation for the product

For each consumer, platform exogenously owns a database q of data records

Each data record is informative about the corresponding consumer's valuation for the merchant product

Only two **types** of records:

- ω_L reveals consumer has valuation 1
- ω_H reveals consumer has valuation 2

Platform's **database** contains:

- 3 million such records
- 6 million such records

A **merchant** sells its product through an e-commerce **platform**

The platform is used by group of **consumers**, each with independent valuation for the product

For each consumer, platform exogenously owns a database q of data records

Each data record is informative about the corresponding consumer's valuation for the merchant product

Only two **types** of records:

- ω_L reveals consumer has valuation 1
- ω_H reveals consumer has valuation 2

Platform's **database** contains:

- 3 million such records
- 6 million such records

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

Merchant chooses price $a \in A$ given information received. He maximizes profits:

$$\pi(a, \omega) = a \mathbb{1}(\omega \geq a)$$

Suppose platform choose information to maximizes consumer's surplus

$$v(a, \omega) = \max\{\omega - a, 0\}$$

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

Merchant chooses price $a \in A$ given information received. He maximizes profits:

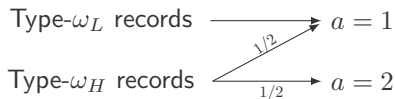
$$\pi(a, \omega) = a \mathbb{1}(\omega \geq a)$$

Suppose platform choose information to maximizes consumer's surplus

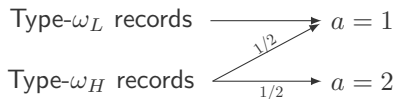
$$v(a, \omega) = \max\{\omega - a, 0\}$$

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

The (unique) optimal recommendation mechanism ($x_q : \Omega \rightarrow \Delta(A)$) is:

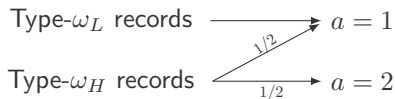


The (unique) optimal recommendation mechanism $(x_q : \Omega \rightarrow \Delta(A))$ is:



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

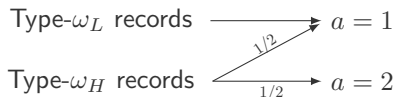
The (unique) optimal recommendation mechanism $(x_q : \Omega \rightarrow \Delta(A))$ is:



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

Are ω_L -records worthless?

The (unique) optimal recommendation mechanism $(x_q : \Omega \rightarrow \Delta(A))$ is:



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

Are ω_L -records worthless? No, **value of data records** is $\psi_q^*(\omega) = \begin{cases} 1 & \text{if } \omega_L \\ 0 & \text{if } \omega_H \end{cases}$

Some observations:

Some observations:

- Most valuable records are those yielding lowest payoff. Why?
- ω_L generates no payoff for platform but “helps” lowering merchant price, thus allowing ω_H to earn positive surplus

Some observations:

- Most valuable records are those yielding lowest payoff. Why?
- ω_L generates no payoff for platform but “helps” lowering merchant price, thus allowing ω_H to earn positive surplus
- Payoff u^* gives *biased* account of the value created by a record **only if** platform withholds information from merchant

$$\psi_q^*(\omega) = u_q^*(\omega) + t^*(\omega)$$

Some observations:

- Most valuable records are those yielding lowest payoff. Why?
- ω_L generates no payoff for platform but “helps” lowering merchant price, thus allowing ω_H to earn positive surplus
- Payoff u^* gives *biased* account of the value created by a record **only if** platform withholds information from merchant

$$\psi_q^*(\omega) = u_q^*(\omega) + t^*(\omega)$$

- **Approach.** Platform uses inputs (data records) to produce outputs (recommendations). GLP '23 use LP duality to **characterize** the **values** of these inputs, namely $\psi_q^*(\omega)$ – platform's willingness to pay for an additional ω -record