Ignorance Is Strength: Improving the Performance of Matching Markets by Limiting Information

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January 2, 2017

Motivation

Example

Uber driver receives a request

- sees the passenger's rating, name and pick-up location
- does not see passenger's destination until after he picks him up
- but drivers care about the destination

Efficient?

Efficiency

- Primary objective for many matching platforms is to facilitate value-creating transactions
- Revealing information brings more surplus to the receiver of the info

Research Questions

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Can a matching platform improve the efficiency of the marketplace by limiting information the buyers and sellers observe about each other before engaging in a match?

What does the optimal disclosure policy depend on?

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Efficiency and supply-demand fit are important issues for companies with platform business model

Examples

- Transportation (e.g. Uber/Lyft, Convoy)
- Housing rental (e.g. Airbnb)
- Labor market (e.g. temp agencies, TaskRabbit)
- Coaching

Details

This paper

Framework for analyzing information intermediation in matching markets

- Model of two-sided matching market with search
- Buyers and sellers have preferences over each other
- The platform is the information intermediary

Preview of Results

1. Full disclosure is inefficient
   - i.e. there is an outcome with both higher buyer and seller surpluses
   - Intuition: revealing information to agents leads to cream-skimming and low match rates

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1. Full disclosure is inefficient
   - i.e. there is an outcome with both higher buyer and seller surpluses
   - Intuition: revealing information to agents leads to cream-skimming and low match rates
2. Characterization of the efficient information disclosure policy. Depends on:
   - the shape of unobserved preference heterogeneity
   - agents' capacity constraints
   - buyer-to-seller ratio

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- Key condition: set of matches that create value for sellers is distinct from the set of matches that create value for buyers

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- Key condition: set of matches that create value for sellers is distinct from the set of matches that create value for buyers

- Platform cares about both sides of the market
- Disclosing more information to sellers reduces the platform's ability to induce sellers to accept the efficient matches
  - Sellers will single out the matches that are valuable to them and reject other matches that can be valuable to the buyers.

Forces behind Inefficiency (2): Same-side Effect

- Sellers are worse off as a whole when
  - have correlated preferences over buyers,
  - have limited capacity for serving buyers, and
  - are forward-looking.
- Info disclosure stimulates sellers to *cream-skim*, i.e. to chase the most valuable buyers and abandon buyers with average value
- Prisoners' Dilemma problem $\Rightarrow$ disclosure leads to inefficiency

Contributions

1. Market/organizational design: Milgrom 2010, Hagiu-Wright 2015, Fradkin 2015, Horton 2015
   - Emphasizes and clarifies the role of information disclosure as a design tool
   - Shape of the disclosure policy is not restricted in any way (cf. Hoppe et al. 2009)
2. Information design literature: Kamenica-Gentzkow 2011, Kolotilin et al. 2015, Bergemann-Morris 2016
   - Technical contribution: approach to solving information disclosure problems with heterogeneous and forward-looking receivers

Other Related Literature

Search and matching in labor: Becker 1973, Shimer-Smith 2000, 01, Kircher 2009

Information disclosure in markets: Akerlof 1970, Hirshleifer 1971, Spence 1973, Anderson-Renault 1999, Hoppe et al. 2009, Athey-Gans 2010, Bergemann-Bonatti 2011, Hagiu-Jullien 2011, Tadelis-Zettelmeyer 2015, Board-Lu 2015

Centralized matching: Roth 2008, Akbarpour et al. 2016

Peer-to-peer markets: Hitsch et al. 2010, Fradkin 2015, Horton 2015

Two-sided markets: Rochet-Tirole 2006, Armstrong 2006, Weyl 2010

Platforms in OR: Ashlagi et al. 2013, Arnosti et al. 2014, Taylor 2016

Outline

Spot Matching Process

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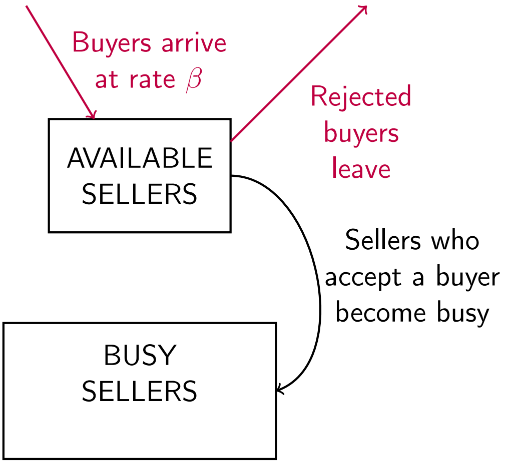

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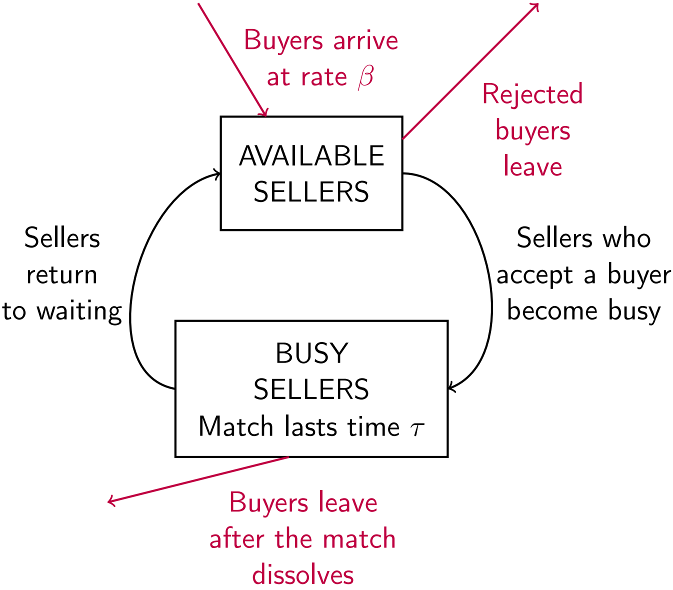

Spot Matching Process, ctd

- Continuous time
- Mass 1 of sellers, always stay on the platform
  - presented with a sequence of buyers at a Poisson rate
  - decides to accept or reject
- Match lasts time τ
  - during which the seller cannot accept new jobs
- Continuum of potential buyers, short-lived
  - gradually arrive at rate β
  - one buyer
- Buyer search is costly:
  - accepted -> buyer stays until the job is completed
  - rejected -> leaves

Assumptions on Matching Process

Assumption

Buyers contact available sellers only.

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- Kircher 2009, Arnosti et al. 2014: focus on friction owing to simultaneity and unavailability

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Assumption

Buyers make a single search attempt

- Simplifying assumption: lost search efforts

Assumptions on Matching Process, ctd

τ – time sellers remain busy after matching
β – buyer arrival rate (mass of buyers per unit of time)

Assumption (No Excess Demand)

Collectively, it is physically possible for sellers to accept all buyers: $\beta\tau < 1$

- Simplifies the notation, otherwise deal with queues
- Extension in the paper

Heterogeneity and Payoffs

$x \in X \subset \mathbb{R}^n$ $x \sim F$, pdf $f > 0$	Buyer characteristics observed by the platform	(passenger destination on Uber)
$u(x) \geq 0$	Buyer match payoff	
$\pi(x)$ continuous $\exists x : \pi(x) > 0$	Seller match payoff	

Platform: Information Disclosure of Buyer Characteristics to Sellers

Platform chooses how to reveal buyer type x to sellers

$S = \Delta(X)$	Set of all posterior distributions over X	
$s \in S$	Platform's "signal" to the seller	(Hypothetical mark to Uber driver "remote neighborhood")
$\lambda \in \Delta(S)$	*Disclosure policy* = distribution of signals	

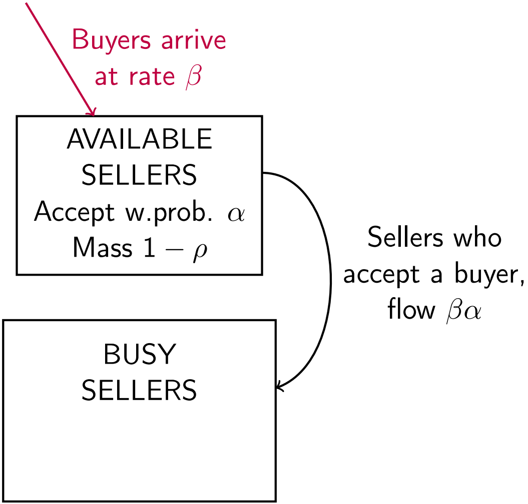
- λ' is *coarser* than λ'' if λ' is less informative than λ''

Steady State of the Matching Process: State Variables

State of the matching system:

1. $\alpha \in [0, 1]$ *acceptance rate*
   - fraction of buyers accepted by an available seller, $\alpha = \lambda(s \text{ is accepted})$
2. $\rho \in [0, 1]$ *utilization rate*
   - fraction of busy sellers

Steady State of the Matching Process: Seller Flows



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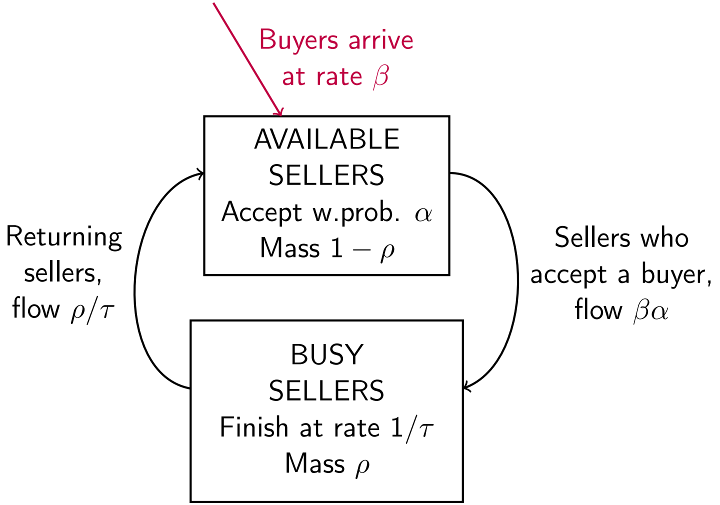

Steady State of the Matching Process: SS Condition

In a steady state, the flows to and from the pool of busy sellers are equal:

$$\beta\alpha = \frac{\rho}{\tau}.$$

Sanity check:

- ρ increases in α, in β, and in τ.

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- β_A – buyer Poisson arrival rate when a seller is available
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- $v(s)$ be the value of a buyer with signal s
  - $v(s)$ includes the option value of rejecting the buyer and the opportunity cost of accepting him
  - $v(s, y) = \max\{0, \pi(s, y) - \tau V(y)\}$

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Seller optimization problem

$$V = \beta_A \int \max\{0, \pi(s) - \tau V)\} d\lambda(s). \quad (1)$$

- No discounting
- $\sigma(s) \colon S \to [0, 1]$ acceptance strategy

Impatient Sellers

Steady-State Equilibrium

(σ, ρ) is a *steady-state equilibrium* if

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2. [SS] σ induces acceptance rate α –> utilization ρ arises in a steady state

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Proposition (1)

Steady-state equilibrium exists and is unique.

Market Design: Information Disclosure

Equilibrium (σ, ρ) is a function of disclosure policy λ

How does equilibrium welfare of each side depend on λ?

Pareto Optimality and Implementability

- Economic outcome $O = (U, V)$ is a combination of buyers' and sellers' surpluses
- An outcome is *feasible* if there is a seller strategy profile that generates it
- A feasible O is *Pareto optimal* if there is no other feasible O' such that $U' > U$ and $V' > V$
- O is *implementable* if there is a disclosure λ such that the equilibrium outcome is O

First Main Result: Inefficiency of the Full Disclosure

V^σ, ρ^σ, U^σ denote steady-state buyers' surplus, sellers' surplus and utilization rate when strategy profile σ is played

Proposition (2)

Let σ^{FD} be the equilibrium strategy profile under full disclosure. Then there exists $\tilde{\sigma}$ such that:

$$\begin{aligned} \tilde{V} &> V^{FD}, \\ \tilde{\rho} &> \rho^{FD}, \\ \widetilde{U} &\geq U^{FD}. \end{aligned}$$

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- Consider $\tilde{\sigma}$ that accepts matches

$$\{x \colon \pi(x) \geq 0\}.$$

  - $\tilde{\sigma}$ additionally accepts $X' := \{x \colon 0 \leq \pi(x) < \tau V^{FD}\}$

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- Sellers are better off under $\tilde{\sigma}$
  - There is x with $\pi(x) > 0 \Rightarrow V^{FD} > 0$
  - X convex, π continuous in $x \Rightarrow X' \neq \varnothing$

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- Buyers are better off under $\tilde{\sigma}$
  - $u(x) \geq 0 \ \forall x$ by assumption

Disclosure Reduces Buyer Surplus: Intuition

- Set of matches that create positive surplus for sellers is distinct from the set of matches that create positive surplus for buyers
- Sellers do not internalize buyer surplus
- Disclosing more information to the sellers reduces the platform's ability to induce them to accept the efficient matches
- Sellers cream-skim: single out the matches that are valuable to them and reject other matches that can be valuable to the buyers

Disclosure Reduces Seller Surplus: Seller Coordination Problem

- Coordination problem, intuitively:
    - a seller keeps his schedule open by rejecting low-value jobs to increase his individual chances of getting high-value jobs
    - as a result in eqm, sellers spend a lot of time waiting for high-value jobs
    - collectively, this behavior is suboptimal because all profitable jobs have to be completed
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  - collectively, this behavior is suboptimal because all profitable jobs have to be completed
    (feasible by No Excess Demand assumption)
- *Cream-skimming externality*: by rejecting a job a seller makes himself available and decreases the other sellers' chances of getting subsequent jobs
- Coordination problem arises because sellers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained

Implementability with Known Seller Preferences

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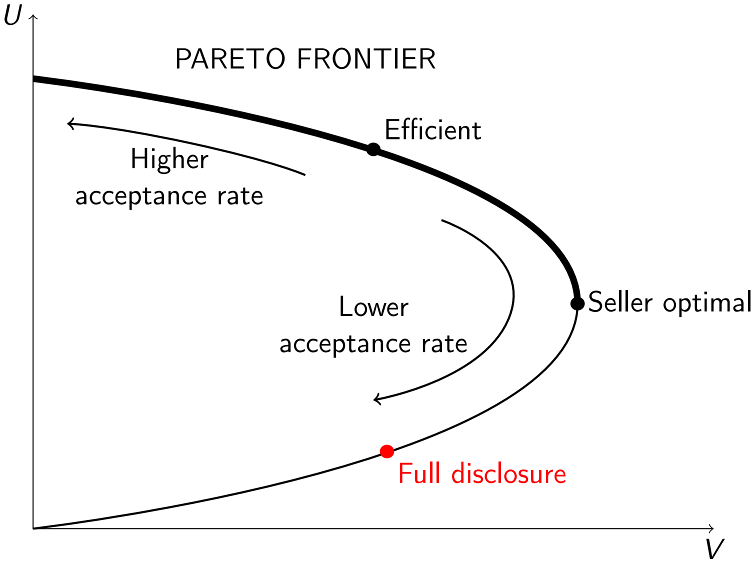
Proof sketch:

1. Platform knows what matches should be made
2. 2 actions -> binary signaling structure is sufficient (Revelation principle)
    - recommend matches to sellers
    - provide no further information
3. The sellers follow the recommendations
    - With binary signaling structure, seller dynamic problem reduces to static problem
    - Pariticipation constrained holds $\Rightarrow$ the value of the recommendation to accept is positive on average

Implementability with Known Seller Preferences



Unobserved Heterogeneity in Seller Preferences

$y \in Y \subset \mathbb{R}^m$ $y \sim G$, pdf $g > 0$	Seller characteristics unobserved by the platform	(driver's preference for long rides)
$x \in X \subset \mathbb{R}^n$ $x \sim F$, pdf $f > 0$	Buyer characteristics observed by the platform	(passenger destination on Uber)
$u(x, y) \geq 0$	Buyer match payoff	
$\pi(x, y)$ continuous	Seller match payoff	

Existence and Inefficiency Remain

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Proposition

Steady-state equilibrium exists and is unique. Full disclosure equilibrium is inefficient.

- Existence and inefficiency by similar reasons
  - Details in the paper

Linear Payoff Environment

- $X = [0, 1]$
    - e.g. remoteness of drop-off location
- $Y = [0, \bar{y}]$
    - e.g. driver's preference for long rides
- $\pi(x, y) = y - x$
- $u(x, y) \equiv u$

Platform's Disclosure Problem

$$\max_{\lambda \in \Delta(S)} \mathcal{J}(\gamma) = \gamma U + (1-\gamma) V$$

- U joint buyer surplus
- V joint seller surplus
- $\gamma \in [0, 1]$
  - $\gamma = 1/2$ total surplus max'n

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Three main challenges for the analysis:

1. The class of information structures is entire $\Delta(S)$
2. Sellers have private payoff types
3. Sellers are forward-looking

Second Main Result: Optimal Disclosure for Uniform Seller Distribution

Definition

The disclosure policy λ is x^**-upper-coarsening* for some $x^* \in [0, 1]$ if λ fully reveals $x < x^*$ and pools all $x > x^*$.

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Proposition (5)

Suppose $G = U[0, \overline{y}]$, $\overline{y} \geq 1$*. Then for any* $\gamma \in [0,1]$*, there is unique* $x^*_\gamma \in [0,1]$ *such that* x^*_γ*-upper-coarsening maximizes* $\mathcal{J}(\gamma)$*.*

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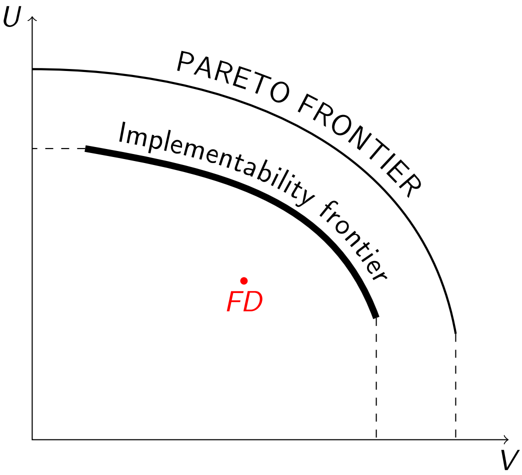
1. *x^*_γ is decreasing in γ.*
2. *There is γ^* and there exist $\beta\tau$ and $\bar{y}$ that are large enough so that $x^*_\gamma < 1$ for $\gamma > \gamma^*$ (some coarsening is strictly optimal).*
3. *If $0 < \beta\tau < 1/2$, then $x^*_\gamma = 1$ for any γ (full disclosure is strictly optimal).*

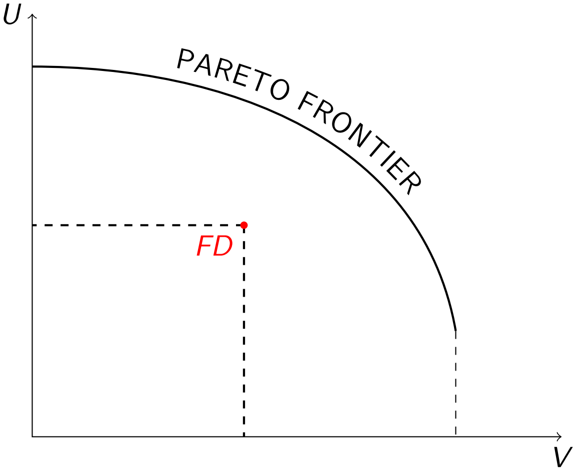
Elaborations

1. More weight on seller surplus (smaller γ) $\Rightarrow$ optimal policy is more revealing
2. When buyer traffic (β) or capacity constraint (τ) is large $\Rightarrow$ optimal to pool high x's
3. When buyer traffic and capacity constraint are small $\Rightarrow$ truthfully reveal all x's

$\beta\tau$ and $\bar{y}$ are large



$\beta\tau \in (0, 1/2)$



Intuition for Optimality of Upper-coarsening

- Buyer traffic (β) or capacity constraint (τ) is large $\Rightarrow$ sellers' option value of rejecting is big
- High buyer types are marginal for high seller types $\Rightarrow$ pooling those buyers makes high sellers accept more
- Low buyer types have relatively smaller option value of rejecting, and less surplus $\Rightarrow$ need to provide information for them to make the right choices

Special Case: Unconstrained Sellers

Benchmark

Suppose $\tau = 0$. Then:

- If g is decreasing, then full disclosure is optimal
- If g is increasing, no disclosure is optimal.
- If g is constant, then disclosure is irrelevant for the matching rate

- Appears e.g. in Kolotilin et al. 2015
- The implied concavification reasoning goes back to Aumann-Maschler 1995 and Kamenica-Gentzkow 2011

Special Case: Unconstrained Sellers

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Intuition: More Detailed

Assume $G = U[0,1]$. Moving to $\tau > 0$ introduces two effects:

1. Endogenous availability
    - High seller types are less available because they accept more
2. Option value of waiting
    - Conceal information to reduce the option value
    - High seller types have larger option value

Proof in Four Steps

Lemma 1: Representation of signaling structures as a particular class of convex functions

Lemma 2: Convenient presentation of the seller dynamic optimization problem

Lemma 3: First order condition of optimality using calculus of variation

Lemma 4: Back out the optimal information structure from the FOC

Representation of Disclosure Policies

- Fix disclosure λ
- $z(s)$ posterior mean of buyer type x after signal s
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$$\Lambda(z;\lambda) := \int_0^z F^{\lambda}(\zeta)\, d\zeta.$$

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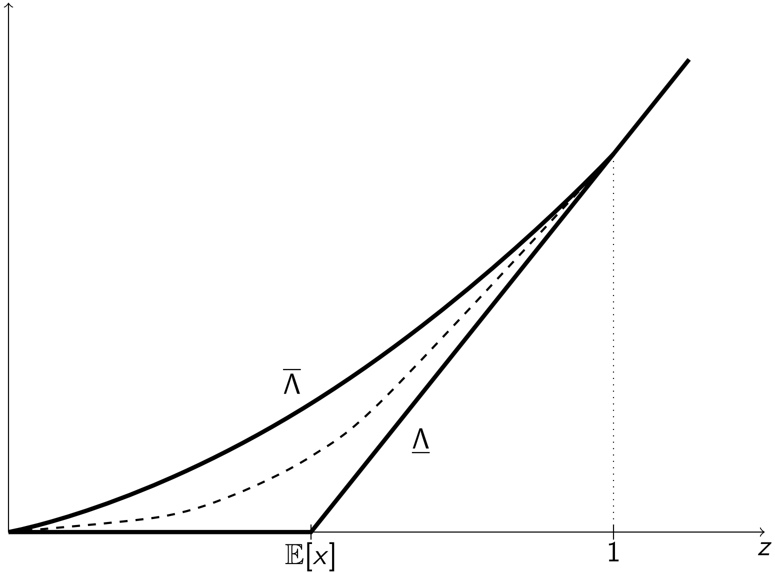
Lemma (1)

A convex function ℓ is point-wise between $\overline{\Lambda}$ and $\underline{\Lambda}$ if and only if there is $\lambda \in \Delta(S)$ such that $\Lambda(\cdot, \lambda) = \ell$.

- e.g. appears in Kolotilin et al. 2015
- Proof idea: Distribution of x is the mean preserving spread of distribution of posterior means of x

Disclosure Policy Representation, ctd



Seller Optimization Problem

- $Z = \left\{\int x\, s(dx) \colon s \in S\right\}$ is the set of posterior means of x

Lemma (2)

For any disclosure policy λ, seller's optimal strategy has a cutoff form with cutoff $\hat{z}(y)$. Furthermore, seller payoff $V(y)$ and the cutoff $\hat{z}(y)$ are solution to:

$$V(y) = \frac{y - \hat{z}(y)}{\tau} = \beta_A \Lambda(\hat{z}(y)).$$

$\Rightarrow$ probability of accepting and seller welfare depends on λ only through Λ

First Order Condition

- Use representation of disclosure policy via Λ
- Use calculus of variations to write down the optimality condition

Lemma (3: Main lemma)

The variational derivative of the match rate M with respect to Λ exists and equals

$$\frac{\delta M}{\delta \Lambda} = K_1 \cdot \left[g(y)\nu'(y) - (g(y)\nu^2(y))' \right],$$

where $K_1 > 0$.

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where $K_1 > 0$. Similarly, the variational derivative of the joint seller profits V with respect to Λ exists and equals

$$\frac{\delta V}{\delta \Lambda} = \frac{\delta M}{\delta \Lambda} \cdot K_2 + \beta_A \nu(y) g(y),$$

where $K_2 > 0$.

Intuition: Uniform Distribution of Seller Type

- Consider $G = U[0,1]$
- Unconstrained sellers ($\tau = 0$),

$$\frac{\delta M}{\delta \Lambda} = 0, \quad \forall \Lambda.$$

- Constrained sellers ($\tau > 0$):

$$\frac{\delta M}{\delta \Lambda} \propto -(\underbrace{(1-\rho(y))^2}_{\text{availability factor}} + \underbrace{\rho(y)}_{\text{continuation value factor}})'.$$

- Additional effects when $\tau > 0$:
  - endogenous availability
  - option value of waiting

Intuition: General Distribution of Seller Type

- Consider general G with pdf g
- Unconstrained sellers ($\tau = 0$),
$$\frac{\delta M}{\delta \Lambda} \propto -g'(y).$$
- Constrained sellers ($\tau > 0$):
$$\frac{\delta M}{\delta \Lambda} = K_1 \cdot \left[g(y)\nu'(y) - (g(y)\nu^2(y))' \right].$$

Back out the Information Structure

Lemma (4)

If λ_0 maximizes $\mathcal{J}$, and $\delta\mathcal{J}/\delta\Lambda$ evaluated at λ_0 crosses 0 from above at most once, then λ_0 is upper-coarsening.

Conclusion

Summary

- Heterogeneous matching market is inefficient when full information is disclosed
    - Information provision stimulates search that leads to inefficiency when search is costly
- The platform can improve efficiency by limiting information exchange to sellers when
    - sellers' preferences are known
    - high buyer-to-seller ratio
    - tight capacity constraints

Further Directions

- Endogenous participation
- Optimal pricing and disclosure to maximize revenue
- Mechanism design vs. information design

Congestion?

In *congested* markets, participants send more applications than is desirable

Reasons for failed matches: screening (20%), mis-coordination (6%), stale vacancies (21%) (Fradkin 2015, on Airbnb data)

1. Screening: rejection due to the searcher's personal or job characteristics
2. Mis-coordination: inquiry is sent to a seller who is about to transact with another searcher
3. Stale vacancy: seller did not update his status to "unavailable"

????, Kircher 2009, Arnosti et al. 2014: mis-coordination
My paper: screening

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Impatient Sellers

Results generalize to the case when the seller has discount rate ρ by changing τ to

$$\tau_\rho = \frac{1 - e^{-\rho\tau}}{\rho}$$

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Examples of Match Quality/Rate Tradeoff

Uber:

- drivers reject requests $\Rightarrow$ passengers wait longer

Airbnb:

- guests (buyers) request services from hosts (sellers)
- ave. #requests is 2.5
- half of request are rejected
- conditional on being rejected from their first request, buyers are 51% less likely to eventually book (Fradkin 2016)

When sellers reject, they slow down the buyer side of the market Back

Examples of Information Coarsening

- Uber: hide passenger destination
- Airbnb: incentivize hosts to accept based on few guest attributes (Instant Book feature)
- TaskRabbit (labor platform): breadth of task categories sellers commit to
- Star ratings: half-star step/10th-of-star step

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