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

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December 23, 2016

Motivation

Example

Uber driver recieves a request

- sees the passanger'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

Question

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 challenges for companies with platform business model

Examples

- Transportation
- Rental housing (e.g. Airbnb)
- Labor market (e.g. temp agencies, TaskRabbit)
- Coaching

Details

This paper

Develops a framework for analyzing information intermediation in two-sided matching markets

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

Preview of Results

1. Economic outcome of heterogeneous matching market is inefficient under the full disclosure
    - there is an outcome with both higher buyer and seller surpluses
    - intuition: disclosure leads to cream-skimming and low match rates

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1. Economic outcome of heterogeneous matching market is inefficient under the full disclosure
   - there is an outcome with both higher buyer and seller surpluses
   - intuition: disclosure leads to cream-skimming and low match rates
2. Characterization of the optimal information disclosure policy that maximizes the weighted average of buyer and seller surpluses
   - depends on the nature of unobserved preference heterogeneity
   - agents' capacity constraints

Forces behind Inefficiency (1): Cross-side Effect

- Imagine the platform releases more information about buyers to the sellers
- Providing information stimulates cream-skimming
- Platform faces a tradeoff between match quality and match rate
  1. holding match rate fixed, info disclosure increases seller match quality
  2. but info disclosure may reveal that the marginal buyer has negative value $\Rightarrow$ match rate $\downarrow$

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  2. but info disclosure may reveal that the marginal buyer has negative value $\Rightarrow$ match rate $\downarrow$
- Sellers do not resolve quality-rate tradeoff efficiently
  - when buyers MRS of quality for rate is higher than of sellers', the match rate is too low $\Rightarrow$ buyers are hurt Examples

- Disclosing more information to sellers reduces the platform's ability to induce sellers to accept the efficient matches

Forces behind Inefficiency (2): Same-side Effect

- Additionally, when sellers
  - have correlated preferences over buyers,
  - have limited capacity for serving buyers, and
  - are forward-looking,
- info disclosure stimulates sellers to chase the most valuable buyers and abandon buyers with average value
- Prisoners' Dilemma problem $\Rightarrow$ further exacerbates cream-skimming

Contributions

1. Search-and-matching models in labor economics: Shimer-Smith 2000, 01, Kircher 2009
    - Empasizes and clarifies the role of information disclosure as a policy intervention
    - 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

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, Milgrom 2010, Akbarpour et al. 2016

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

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

Spot Matching Process

Spot Matching Process

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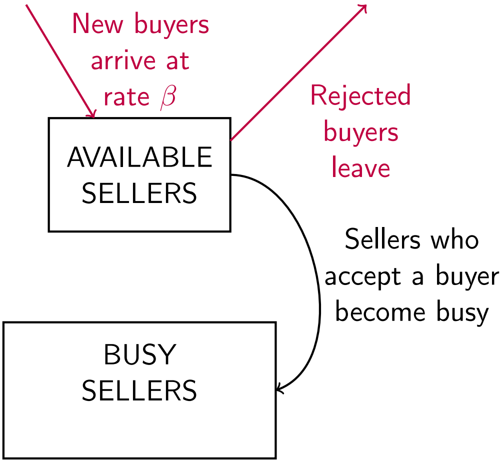

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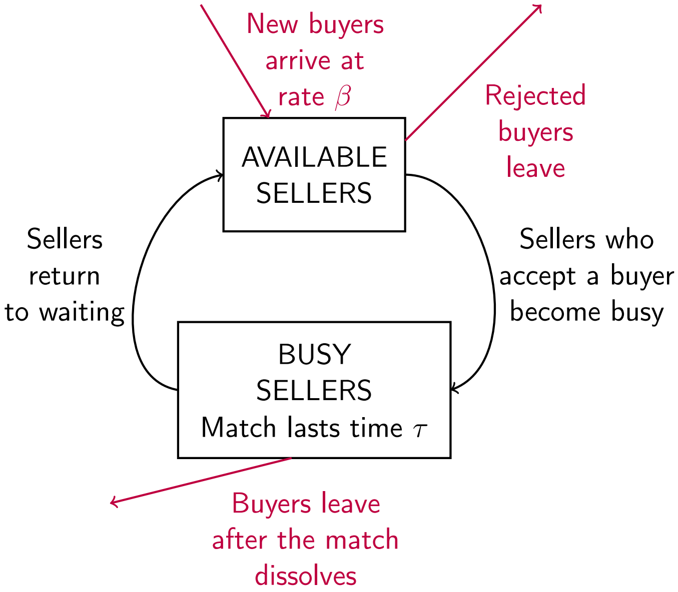

Spot Matching Process, ctd

- 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.

- I focus on search frictions due to preferences heterogeneity
- 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 complete every buyer job: $\beta\tau < 1$

- Simplifies the notation, otherwise deal with queues
- Easy 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)
$y \in Y \subset \mathbb{R}^m$ $y \sim G$, pdf $g > 0$	Seller characteristics unobserved by the platform	(driver's preference for long rides)
$u(x, y) \geq 0$	Buyer match payoff	
$\pi(x, y)$ continuous	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
  - $s \in S$ is platform's "signal" to the seller

- $\mu \in \Delta(S)$ *disclosure policy*
  - = distribution of posteriors
  - $\mu(s)$ fraction of buyers with signal s
- μ' is *coarser* than μ'' if μ' is less informative than μ''

Steady State of the Matching Process

State of the matching system:

1. $\alpha(y) \in [0, 1]$ *acceptance rate*
   - fraction of buyers accepted by available type-y seller, $\alpha(y) = \mu(s \text{ is accepted by } y \mid y \text{ is available})$
2. $\rho(y) \in [0, 1]$ fraction of time type-y seller is busy
   - *utilization rate* of type-y sellers
   - Seller's constrained resource is time

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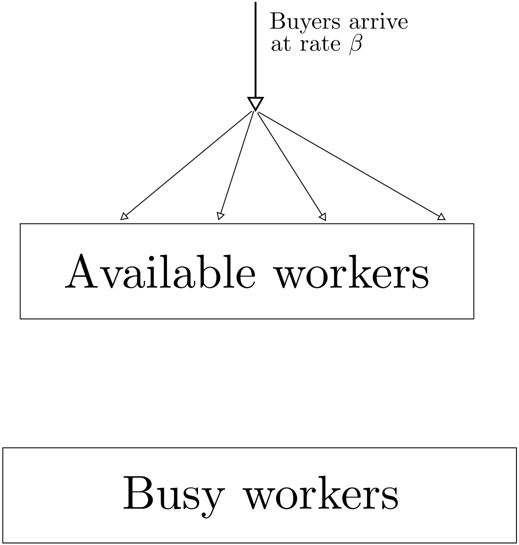
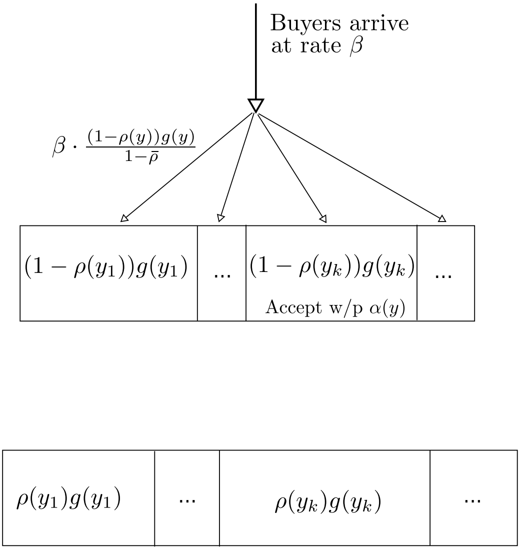


Steady State of the Matching Process

- $g(y)$ mass of y-sellers
- $\rho(y)$ utilization rate of y
- $\bar{\rho}$ average utilization



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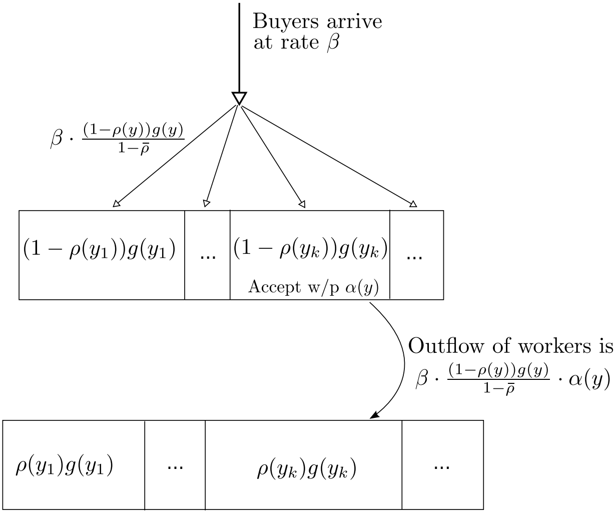

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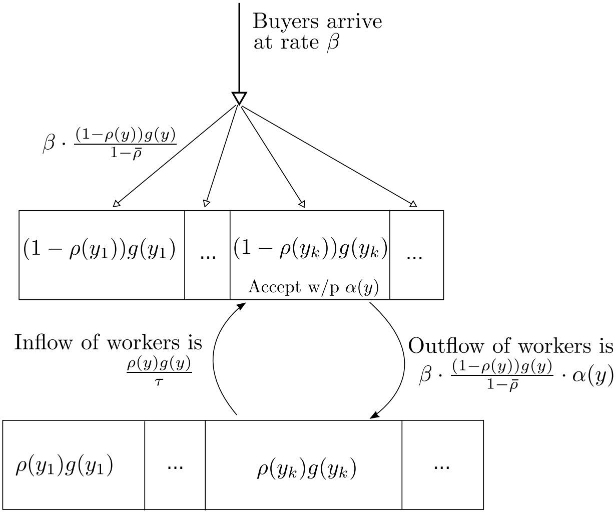

Steady State of the Matching Process

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

$$\beta \frac{(1-\rho(y))g(y)}{1-\bar{\rho}} \alpha(y) = \frac{\rho(y)g(y)}{\tau}, \quad \forall y \in Y.$$

Solution

Average utilization rate $\bar{\rho} \in [0,1]$ is a solution to

$$1 = \int \frac{dG(y)}{1-\bar{\rho}+\beta\tau\alpha(y)}$$

$\bar{\rho}$ increases in $\alpha(y)$ for any $y \in Y$, in β and in τ

Seller Repeated Search Problem

- β_A – buyer Poisson arrival rate when a seller is available
  - $\beta_A = \frac{\beta}{1-\bar{\rho}}$ is endogenous b/c mass of available sellers is endogenous
- $\pi(s,y) := \int_X \pi(x,y)\, s(dx)$ expected profit for seller y of job with signal s
- Every time a job with signal s arrives, seller y gets $v(s,y)$
  - $v(s,y)$ includes option value of rejecting and opportunity cost of being unavailable
- $V(y)$ per-moment value of being available, in the optimum

Seller optimization problem

$$\begin{cases} v(s,y) = \max\{0, \pi(s,y) - \tau V(y)\} \\ V(y) = \beta_A \int v(s,y)\, \mu(ds) \end{cases}$$

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

Impatient Sellers

Steady-State Equilibrium

$(\sigma, \bar{\rho})$ is a *steady-state equilibrium* if

1. [Optimality] Every available seller takes as given Poisson arrival rate $\beta_A = \beta/(1-\bar{\rho})$ and acts optimally –> σ
2. [SS] σ induces acceptance rates $\alpha(\cdot)$ –> utilization $\bar{\rho}$ arises in a steady state

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Proposition (1)

Steady-state equilibrium exists and is unique.

Market Design: Information Disclosure

Equilibrium $(\sigma, \bar{\rho})$ is a function of disclosure policy μ

How does equilibrium welfare of each side depend on μ?

Pareto Optimality and Implementability

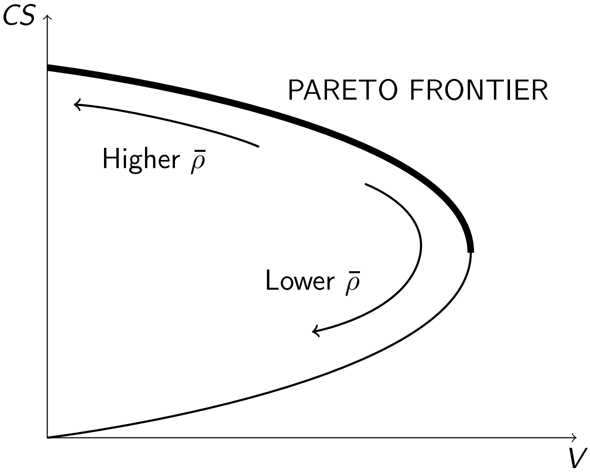
- Market outcome $O = (\{V(y)\}, CS)$ is a combination of seller profits and consumer surplus
- Market outcome is *feasible* if
  1. there are acceptance strategies for sellers that generate it, and
  2. $V(y) \geq 0$ for all y
- A feasible O is *Pareto optimal* if there is no other feasible O' such that $V(y)' > V(y)$ for all y, and $CS' > CS$
- O is *implementable* if there is a disclosure μ such that the equilibrium outcome is O

Implementability for Identical Sellers

Proposition (2)

Suppose sellers are identical. Then any point on the Pareto frontier is implementable by information disclosure.

Implementability for Identical Sellers, ctd



Implementability for Identical Sellers

Proposition (2)

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Proof sketch:

1. 1 seller type, 2 actions -> binary signaling structure is sufficient (Revelation principle)
   - signal = "action recommendation"
   - $X = X_{acc} \cup X_{rej}$
2. With binary signaling structure, seller dynamic problem reduces to static problem
3. Obedience holds because the seller gets V on X_{acc} and $V \geq 0$ by feasibility

Seller Coordination Problem

- Back to general Y

Seller Coordination Problem

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- $V^{\sigma}(y)$, $\rho^{\sigma}(y)$, CS^{σ} denote steady-state profits, utilization rates and consumer surplus when strategy profile σ is played

Proposition (3)

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

$$\begin{aligned} \tilde{V}(y) &> V^{FD}(y), \\ \tilde{\rho}(y) &> \rho^{FD}(y), \\ \widetilde{CS} &\geq CS^{FD}. \end{aligned}$$

Seller Coordination Problem, ctd

- 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
    (feasible by No Excess Demand assumption)

- *Scheduling externality*: by rejecting a job a seller makes himself available and decreases the other sellers' chances of getting subsequent jobs

- Fundamentally, sellers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained

Proof Sketch

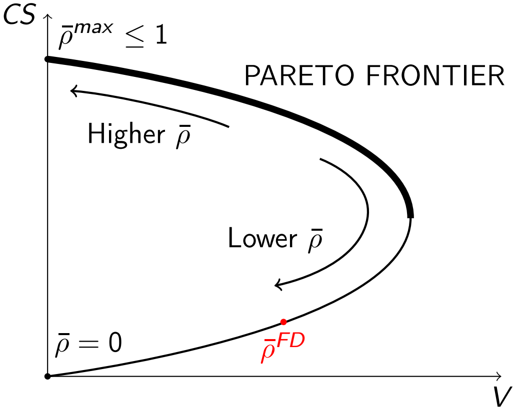
For the case of identical sellers

1. X convex, π continuous in $x \Rightarrow V > 0$
2. Individually:
   - Seller's option value of rejecting is

     $$\tau V > 0$$

   - in eqm, accepted jobs have profit $\pi \geq \tau V$
   - all profitable jobs are $\pi \geq 0$
   - so, some profitable jobs are rejected
3. Collectively:
   - no capacity constraint in aggregate => zero option value of rejecting
   - accepted jobs have $\pi \geq 0$

Seller Coordination Problem, Identical Sellers



Implement a Pareto improvement with heterogeneous sellers?

- Generally not -> next section

Linear Payoff Environment

- $X = [0, 1]$
  - e.g. job difficulty
- $Y = [0, \bar{y}]$
  - e.g. seller skill
- $\pi(x, y) = y - x$
- Platform does not elicit y

Maximal #Matches

- Imagine the platform is growing and wants to maximize #matches
- What is the optimal disclosure policy?
- Equivalent to maximizing capacity utilization:

$$\max_{\mu \in \Delta(S)} \bar{\rho}$$

- Buyer-optimal outcome

The problem is not trivial because:

1. sellers are heterogeneous
2. seller availability is endogenous
3. disclosure affects sellers' option value of rejecting

Static Case

Benchmark

Suppose $\tau = 0$ (static setting). Then:

- If g is decreasing, then full disclosure is optimal
- If g is increasing, no disclosure is optimal.
- If g is constant, then utilization rate is information neutral

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

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Optimal Disclosure for Uniform Seller Distribution

Definition

Disclosure μ is x^*-*upper-censorship* for $x^* \in [0, 1]$ if μ reveals $x < x^*$ and pools all $x > x^*$

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Proposition (4)

Assume $G = U[0, \bar{y}]$. Then there is unique $x^* \in X$ such that x^*-upper-censorship is optimal.
Furthermore,

- *if $\beta\tau < 1/2$, then $x^* = 1$ (full disclosure is strictly optimal)*
- *if $\bar{y}$ is large enough, then there is $\chi^* \in (1/2, 1)$ such that if $\beta\tau > \chi^*$, then $x^* < 1$ (some coarsening is strictly optimal)*

Intuition

Additional effects in dynamic matching:

- availability effect
  - high types accept more jobs -> less available -> pdf of available sellers is decreasing
  - -> motivation for platform to reveal x
- patience effect
  - high types have larger pool of profitable jobs -> larger opportunity cost of accepting
  - -> motivation for platform to conceal high x's
  - overcomes availability effect when there are very high seller types (large $\bar{y}$) and strong buyer traffic (large β)

Optimality of Information Coarsening: General G

Proposition (5)

There is $\xi^* \in \mathbb{R}$ such that if

$$g'(\bar{y})/g(\bar{y}) > \xi^*,$$

then full disclosure is sub-optimal. Furthermore, if $\bar{y}$ is large enough, then there is $\chi^* \in (1/2, 1)$ such that if

$$\beta\tau > \chi^*,$$

then $\xi^* < 0$.

Seller Optimization Problem

- $Z = \left\{ \int x \, s(dx) \colon s \in S \right\}$ is the set of posterior means of x
- $F^{\mu}(\zeta) = \mu \left\{ \int x \, s(dx) \leq \zeta \right\}$ is the cdf of posterior means of x under μ

Lemma (1)

For any disclosure policy μ, seller's optimal strategy has a cutoff form. Furthermore, seller cutoff $\hat{z}(y)$ is the solution to:

$$y - \hat{z}(y) = \tau \beta_A W^{\mu}(\hat{z}(y))$$

where

$$W^{\mu}(z) := \int_0^z (z - \zeta) dF^{\mu}(\zeta)$$

is the option value function.

Disclosure Policy Representation

- $\overline{W}$ option value function under full disclosure,

$$\overline{W}(z) := \int_0^z F(\xi)d\xi.$$

- $\underline{W}$ be the option value function under no disclosure,

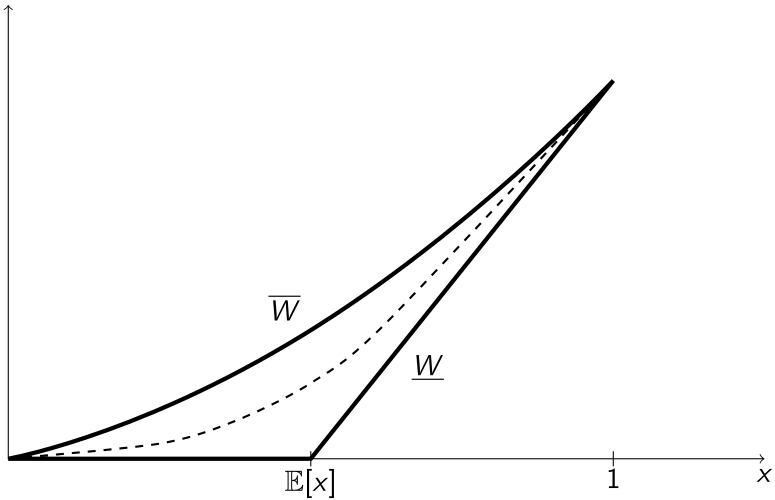
$$\underline{W}(z) := \max\{0, z - \mathbb{E}[x]\}.$$

Lemma (2)

Option value function W is implementable by some disclosure policy if and only if W is a convex function point-wise between $\overline{\Lambda}$ and $\underline{\Lambda}$.

- 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



First Order Condition

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

Lemma (3: Main lemma)

The first variation of $\bar{\rho}$ with respect to W exists and is proportional to:

$$\frac{\delta \bar{\rho}}{\delta W} \propto -\left(g(y)(1-\rho(y))^2\right)' - g(y)\rho'(y).$$

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Corollary

Suppose $\tau = 0$ (static setting). Then

$$\frac{\delta \bar{\rho}}{\delta W} \propto -g'(y).$$

If G is concave, then full disclosure is optimal. If G is convex, no disclosure is optimal.

Intuition: Uniform Distribution of Seller Skill

- Consider $G = U[0, 1]$
- In statics ($\tau = 0$),
$$\frac{\delta \bar{\rho}}{\delta W} = 0, \quad \forall W.$$
- If $\tau > 0$,
$$\frac{\delta \bar{\rho}}{\delta W} \propto -(\overbrace{\underbrace{(1-\rho(y))^2}_{\text{availability factor}} + \underbrace{\rho(y)}_{\text{patience factor}}}^{\text{"adjusted density"}})'.$$
- Additional effects:
  - availability effect
  - patience effect

Proof of Proposition 4

Sketch

1. Need to show that at $\overline{\Lambda}(y)$, there is deviation $\delta W(y)$ such that $\delta\bar{\rho} > 0$.
2. $\frac{(\rho(y)-\rho(y)^2)'}{(1-\rho(y))^2} < \frac{g'(y)}{g(y)}$ for some interval of y's
3. LHS decreasing in y so take $\delta W(y)$ such that $\delta W(\bar{y}) < 0$

Optimality of Full Disclosure

Proposition (6: Sufficient condition for local optimality of full disclosure)

If G is concave, and $\beta\tau < 1/2$, then it's impossible to improve upon full disclosure by "local coarsening".

Optimality of No Disclosure

Proposition (7: Necessary condition for optimality of no disclosure)

If

$$g'(y) < g(\mathbb{E}x)\tau\beta(1-\beta\tau)^2, \quad \forall y,$$

then no disclosure is suboptimal.

Conclusion

Summary

- In decentralized matching markets, there is a problem of excessive search
  - one side does not internalize time value and search efforts of the other side
- Information disclosure has competing effects
  1. Individual Choice Effect (pushes for more disclosure)
  2. Cross-Side Effect (pushes for less disclosure)
  3. Strategic Same-side Effect (pushes for less disclosure)
- There is efficiency-improving information coarsening when
  - identical sellers
  - heterogeneous sellers but high buyer-to-seller ratio
  - heterogeneous sellers but tight capacity constraints

Further Directions

- Optimal pricing and disclosure to maximize revenue
- Endogenous participation and membership prices
- Non-information design
    - Limits on acceptance rate
    - Ranked sellers

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

▸ Back

Impatient Sellers

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

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

Back

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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