Ignorance is Strength: Improving Performance of Decentralized Matching Markets by Limiting Information

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Decentralized Matching Markets

- Rental housing
- Transportation
- Labor market
- Dating
- Coaching, massage
- etc.

An important source of market failure is *excessive screening*

Buyers and sellers want to find the most valuable options

It is also important that matches happen fast

Rejections Matter

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)

Uber:

- drivers reject requests -> passengers wait longer

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

Excessive Screening

- In matching markets, sellers have non-trivial preferences over buyers
- Seller reject (screen) buyers that are not a good fit
    - 20% of inquiries are screened (Fradkin 2015)
- If buyer welfare is not internalized by sellers, the marketplace is inefficient due to *excessive screening*

	Screened buyer attributes	Seller attributes
Airbnb	gender, age, socio-economic status, race, personality, messiness, etc	preference for age, race, personality
Uber	rider destination	home location / preference for long rides / tolerance to traffic congestion
Any platform	Star rating	

Information Disclosure

- Approach the problem using the information design (Bergemann-Morris series)

Question

Can the platform design an information intermediation policy to alleviate the excessive screening problem and improve efficiency?
What does the optimal disclosure policy depend on?

- E.g. on Airbnb
  - What guest attributes should be made visible and others less visible?
  - How much communication between hosts and guests should be allowed?

Preview of Results: Effects of Information Disclosure

Three competing effects:

1. Individual Choice Effect: Each seller wants to be maximally informed about buyer characteristics
2. Cross-side Delaying Effect: Information availability increases perceived diversity of buyers $\Rightarrow$ sellers screen more $\Rightarrow$ buyers are harmed
3. Same-side Option Value Effect: Information availability increases perceived diversity of buyers $\Rightarrow$ sellers chase the very best buyers $\Rightarrow$ sellers are harmed

"1" pushes for more disclosure, "2" and "3" push for less disclosure

Non-technical Preview of Results: Coarse Information Disclosure

- Identical sellers -> coarsen
  - picky sellers -> Cross-side Effect is strong -> coarsen info
  - patient sellers -> Strategic Effect is strong -> coarsen info
- Heterogeneous sellers -> Ind. Choice Effect is strong -> more info
  But if additionally,
  - high buyer-to-seller ratio -> Strategic Effect is strong -> coarsen info
  - tighter capacity constraints -> Strategic Effect is strong -> coarsen info

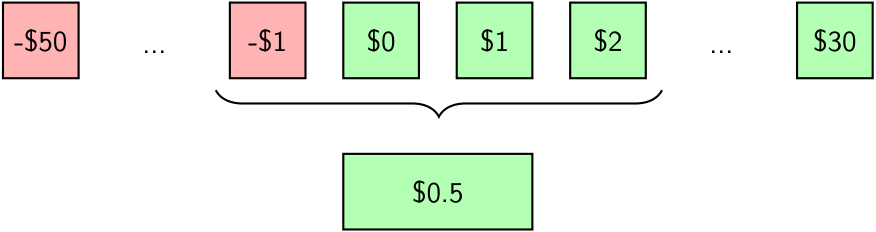
Examples of Coarse Information

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

What is Efficiency Improving Information Coarsening?

Intuition for static matching with 1 seller

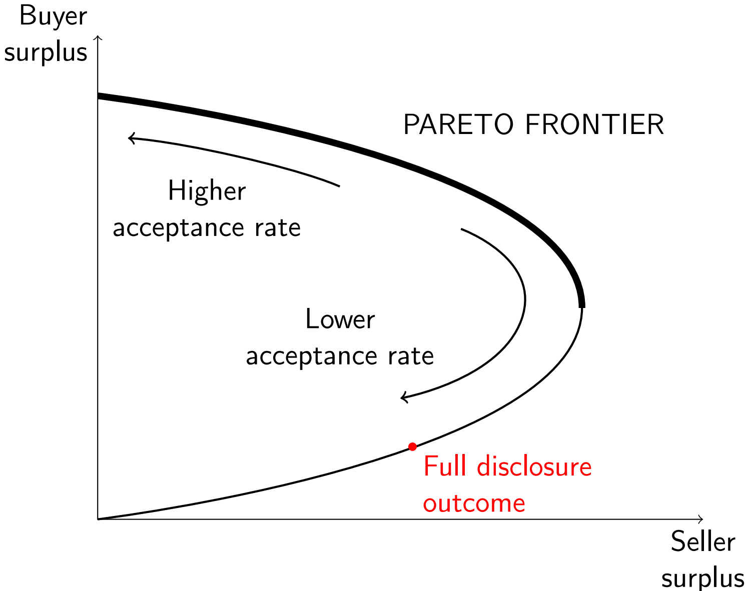
- How does information coarsening improve welfare?
- Based on standard information disclosure literature (Aumann-Maschler 1995, Kamenica-Gentzkow 2011)



Preview of Results: Talk Outline

1. Model of a decentralized matching market in which buyers arrive over time and pursue sellers by proposing jobs. Sellers have heterogeneous preferences over jobs and independently decide what jobs to accept
2. Identical sellers -> information disclosure policies implement any point on the Pareto frontier in axes of buyer surplus and seller surplus
3. Unmediated market -> market outcome is Pareto dominated due to *scheduling externality*
    - Unmediated = full disclosure
4. Optimal disclosure in linear payoff environment to maximize #matches. Coarsen information if
    - there are more high-skill sellers than low-skill sellers
    - higher buyer-to-seller ratio
    - capacity constraints are more severe

Preview of Results: Talk Outline



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Related Literature

Two-sided markets: Rochet-Tirole 2006, Armstrong 2006, Weyl 2010, Hagiu-Wright 2015

Communication games: Blackwell 1953, Aumann-Maschler 1995, Kamenica-Gentzkow 2011, Kolotilin et al. 2015, Bergemann et al. 2015

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

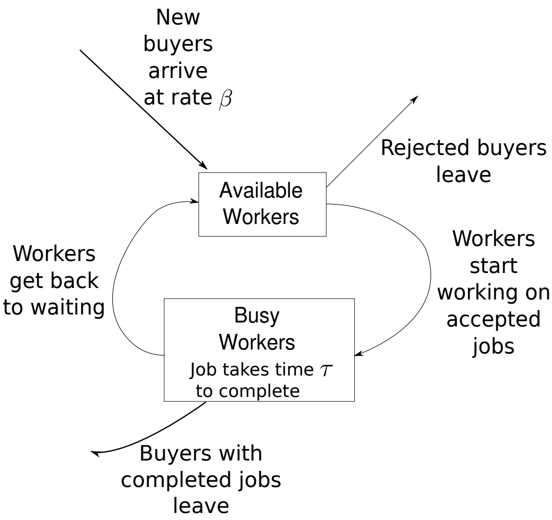
Matching in Labor: Becker 1973, Shimer-Smith 2000, Kircher 2009

Market Design: 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, ctd

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

Assumptions on Matching Process

Assumption

Buyers make a single search attempt

- Simplifying assumption: lost search efforts

Assumption (No Coordination Frictions)

Buyers are directed to available sellers only

- I focus on search frictions due to preferences heterogeneity
- Kircher 2009, Arnosti et al. 2014: focus on coordination frictions

Assumption (Homogeneous Buyer Preferences)

Buyers contact an available seller chosen uniformly at random

- Relaxed in an extension in the paper

Assumptions on Matching Process, ctd

τ – time to complete any job
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 net match payoff	
$\pi(x, y)$ continuous	Seller net match payoff	

Intermediary: 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

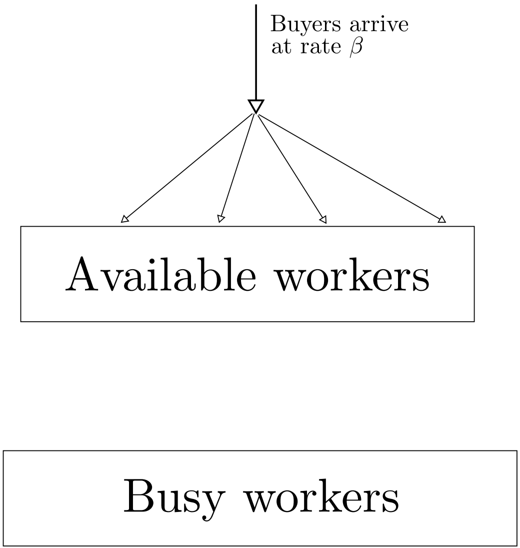
- $\mu \in \Delta(S)$ *disclosure policy*
  - = distribution of posteriors
  - $\mu(s)$ fraction of buyers with signal s
- μ' is *coarser* than μ'' if μ' is a Blackwell-garbling of μ''

Steady State of the Matching Process

State of the matching system:

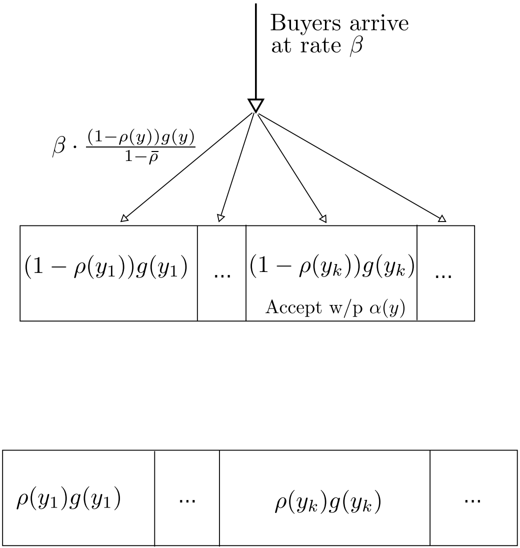
1. $\alpha(y) \in [0, 1]$ *acceptance rate*
   - fraction of jobs accepted by available type-y seller, $\alpha(y) = \mu(s \text{ is accepted by } y \mid y \text{ is available})$
2. $\rho(y) \in [0, 1]$ fraction of time type-y seller is busy
   - *utilization rate* of type-y sellers
   - Seller's constrained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

Steady State of the Matching Process



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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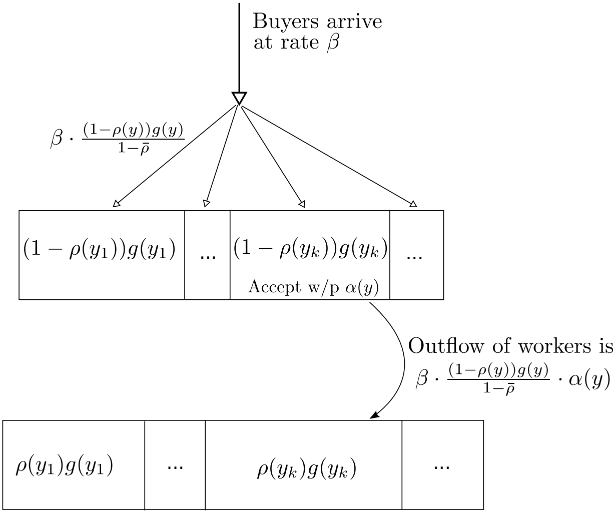

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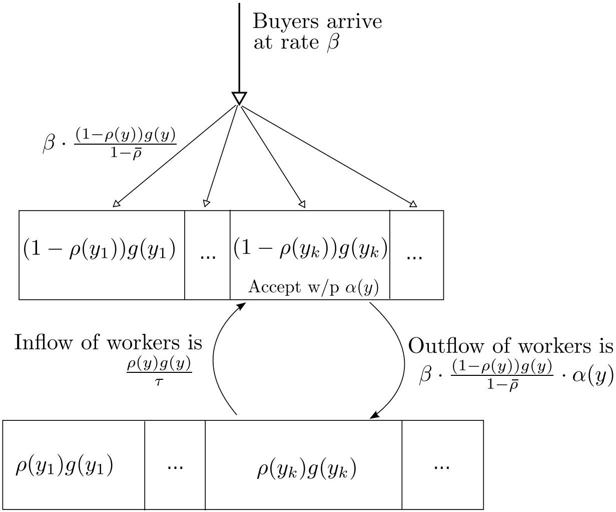


Steady State of the Matching Process

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

Impatient Sellers

- $\sigma(s, y)\colon S \to [0, 1]$ acceptance strategy

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

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

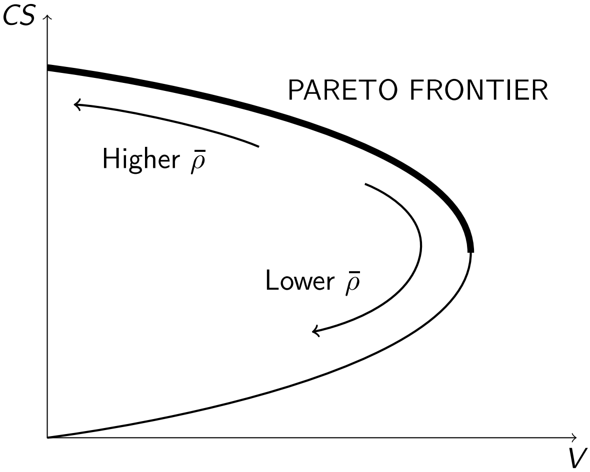
Proposition (2)

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

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

Implementability for Identical Sellers, ctd



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Seller Coordination Problem

- Back to general Y
- $V^{\sigma}(y)$, $\rho^{\sigma}(y)$, 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

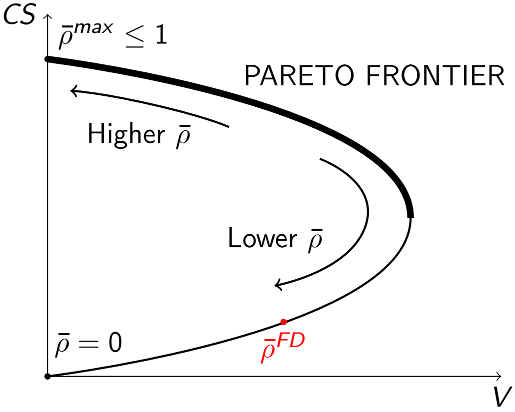
- Fundamentally, sellers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained

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

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 $x > x^*$

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,

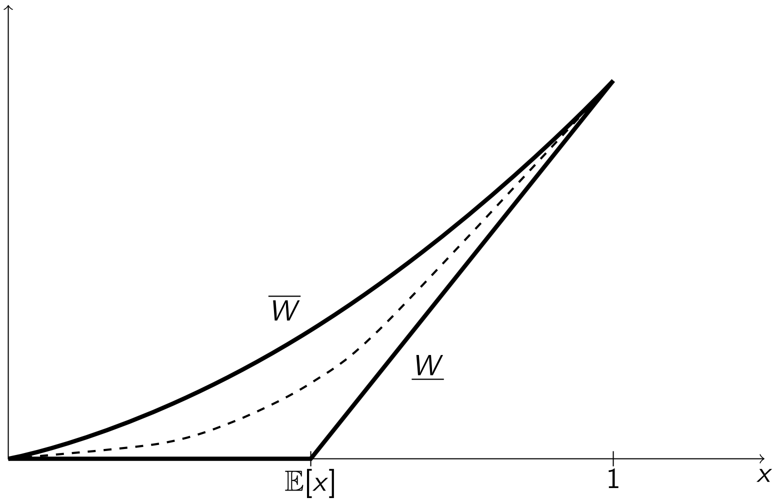
$$\underline{W}(z) := \max\{0, z - \mathbb{E}[x]\}.$$

Lemma (2)

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

- 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:

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

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 $\overline{W}(y)$, 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"

Burdett et al. 2001, 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