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

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Decentralized Matching Markets: Airbnb

- Airbnb connects guests (buyers) and hosts (sellers)
- Both guests and hosts have preferences over the other side
- Guests search actively, hosts search passively (screen)

Excessive Search

- When hosts reject, they slow down the guest side of the market – guest time and search effort is wasted
- 20% of inquiries are screened by hosts (Fradkin 2015)
  - add other reasons for rejection -> 49% of inquiries are rejected

- Welfare = total match value plus disutility from search
- If guest search efforts are not internalized by hosts, the marketplace is inefficient due to *excessive search*

Information Disclosure

- Approach the problem using the information design (Bergemann-Morris series)
- Airbnb controls information hosts and guests can learn about each other

Question

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

- E.g. hosts screen guests based on guest gender, socio-economic status, daily schedule, race, personality, messiness, star rating, reviews, etc.
- 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:

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1. Individual Choice Effect: Hosts want to be informed about guest characteristics (Blackwell 1953)
2. Cross-side Effect: Information availability increases perceived diversity of guests -> hosts screen more -> matches take longer to form
3. Strategic Same-side Effect: Information availability increases perceived diversity of guests -> workers wait around for the best guests -> matches take longer to form (*scheduling externality*)

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

Non-technical Preview of Results: Coarse Information Disclosure

- Identical workers
  - picky workers -> Cross-side Effect is strong -> coarsen info
  - patient workers -> Strategic Effect is strong -> coarsen info

- Heterogeneous workers -> Ind. Choice Effect is strong -> more info
  But if additionally,
  - high buyer-to-worker ratio -> Strategic Effect is strong -> coarsen info
  - tighter capacity constraints -> Strategic Effect is strong -> coarsen info

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Applications

- 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 workers commit to

Cross-side Effect

Intuition for static matching with 1 worker

- How does information coarsening trade off buyer and worker surplus?
- Based on standard information disclosure literature (Aumann-Maschler 1995, Kamenica-Gentzkow 2011)

-$50	...	-$1	$0	$1	$2	...	$30

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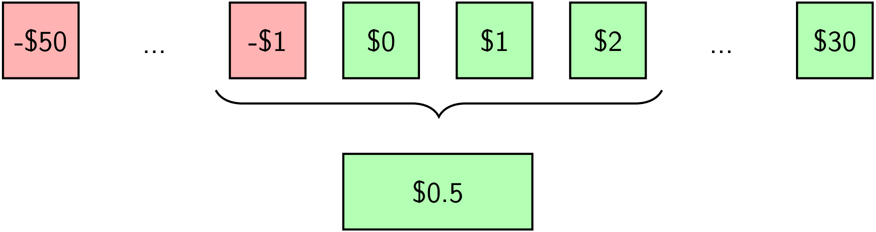

Preview of Results: Talk Outline

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3. Unmediated market -> market outcome is Pareto dominated due to *scheduling externality*
   - Unmediated = full disclosure

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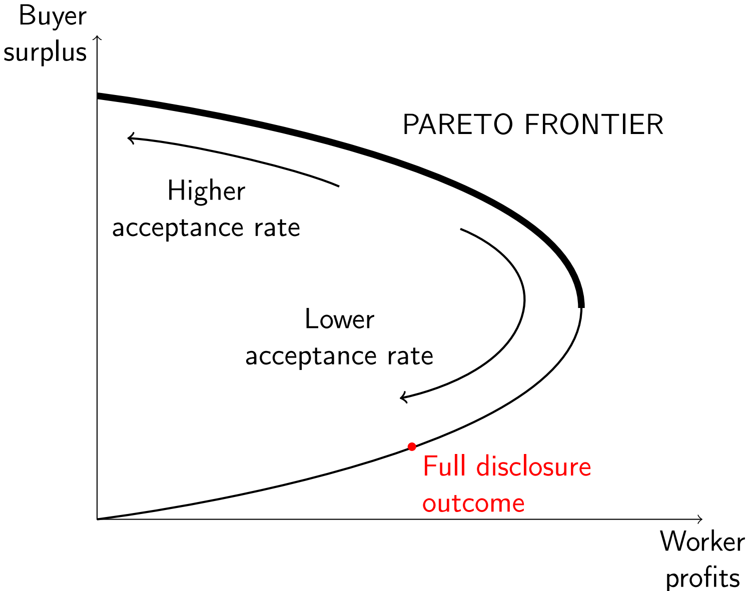

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2. Identical workers -> information disclosure policies implement any point on the Pareto frontier in axes of buyer surplus and worker surplus
3. Unmediated market -> market outcome is Pareto dominated due to *scheduling externality*
   - Unmediated = full disclosure
4. Optimal disclosure in linear payoff environment to maximize #matches. Coarsen information if
   - there are more high-skill workers than low-skill workers
   - higher buyer-to-worker ratio
   - capacity constraints are more severe

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, Anderson-Renault 1999, Hoppe et al. 2009, Athey-Gans 2010, Bergemann-Bonatti 2011, Tadelis-Zettelmeyer 2015, Board-Lu 2015

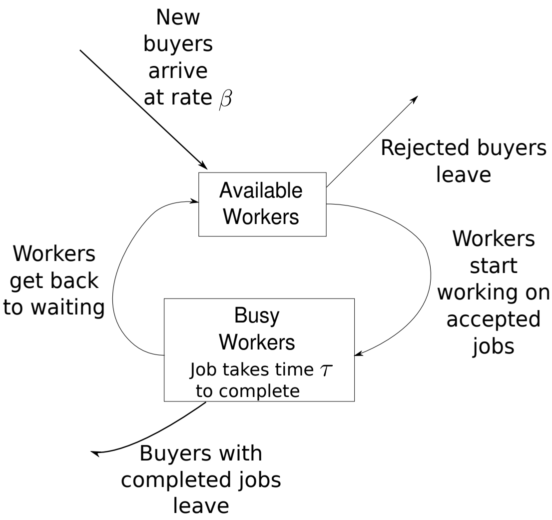
Matching in Labor: Becker 1973, Shimer-Smith 2000, Kircher 2009

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 workers, 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 worker 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

Heterogeneity and Payoffs

	Buyers	Workers
Payoff types	$x \in X \subset \mathbb{R}^n$	$y \in Y \subset \mathbb{R}^m$
Cdf, pdf	$F,\ f > 0$	$G,\ g > 0$
1-match net payoff (net of prices)	$u(x, y) \geq 0$	$\pi(x, y) \gtrless 0$
Outside option	0	0

- X, Y – convex subsets of Euclidean spaces
- $F(x)$ and $G(y)$ have full support
- $\pi(x, y)$ continuous
- $\min_x \pi(x, y) < 0 < \max_x \pi(x, y)$ for all y
- $u(x, y) \geq 0$ for any x, y

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 workers only

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

Assumption (Homogenous Buyer Preferences)

Buyers contact an available worker 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 workers to complete every buyer job: $\beta\tau < 1$

- Simplifies the notation, otherwise deal with queues
- Easy extension in the paper

Intermediary: Information Disclosure

Information structure:

- Platform observes buyer type x but not worker type y
- Worker observes his y but not x

Platform chooses how to reveal x to workers

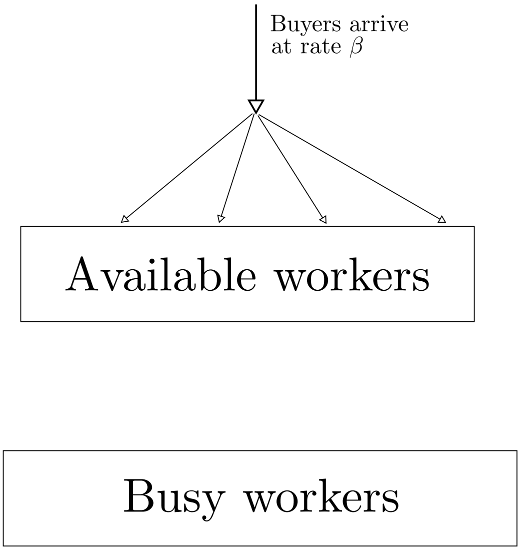
- $S = \Delta(X)$ set of all possible signals
  - $s \in S$ is posterior distribution of x
- $\mu \in \Delta(S)$ disclosure policy
  $=$ distribution of posteriors
- Platform does not elicit y

Steady State of the Matching Process

State of the matching system:

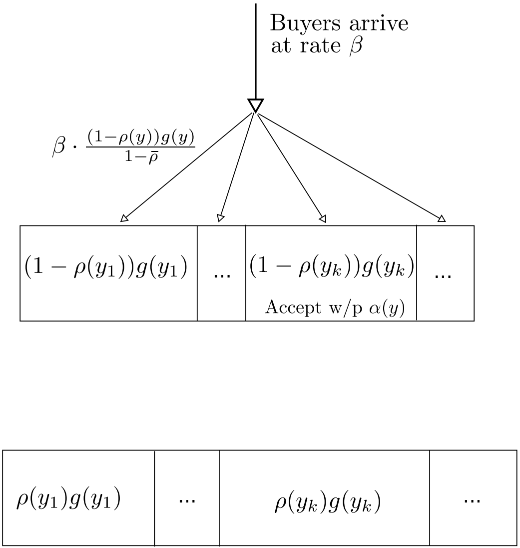
1. $\alpha(y) \in [0, 1]$ *acceptance rate*
   - fraction of jobs accepted by available type-y worker, $\alpha(y) = \mu(s \text{ is accepted by } y | y \text{ is available})$
2. $\rho(y) \in [0, 1]$ fraction of time type-y worker is busy
   - *utilization rate* of type-y workers
   - Worker's constrained 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-workers
- $\rho(y)$ utilization rate of y
- $\bar{\rho}$ average utilization



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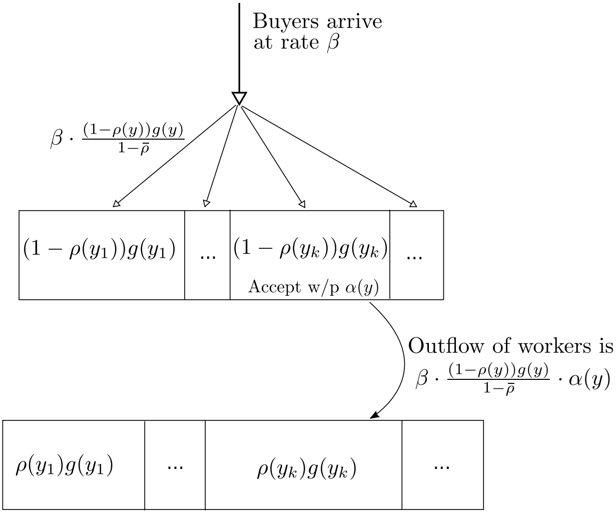

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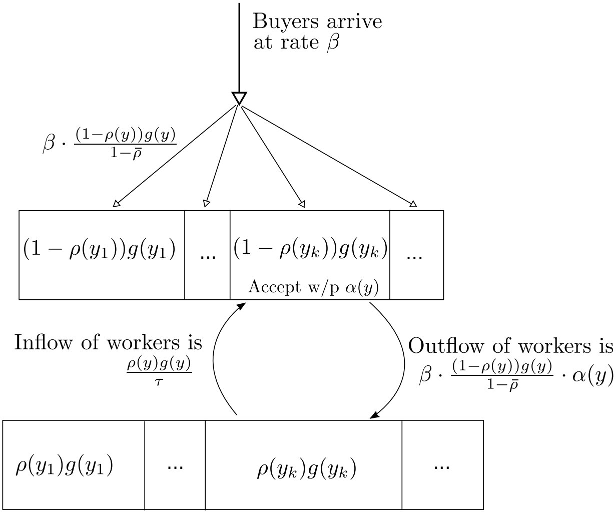

Steady State of the Matching Process

In a steady state, the flows to and from the pool of busy workers 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

Worker Repeated Search Problem

- β_A – buyer Poisson arrival rate when a worker is available
  - β_A is endogenous b/c mass of available workers is endogenous
- $\pi(s, y) := \int_X \pi(x, y)\, s(dx)$ expected profit for worker y of job with signal s
- Every time a job with signal s arrives, worker 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

Worker 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 Workers

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

Steady-State Equilibrium

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

1. [Optimality] Every available worker 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

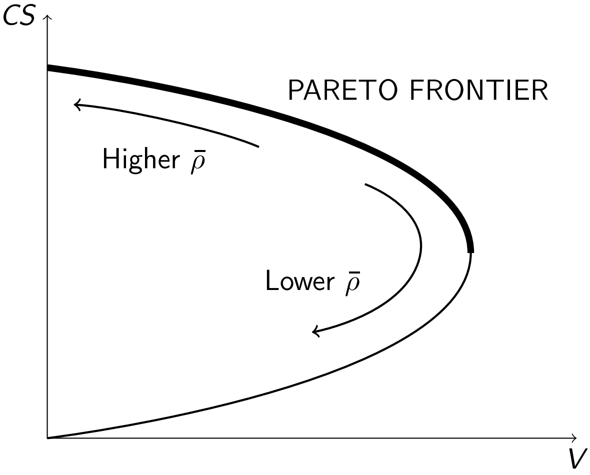
- Market outcome $O = (\{V(y)\}, CS)$ is a combination of worker profits and consumer surplus
- Market outcome is *feasible* if
  1. there are acceptance strategies for workers that generate it, and
  2. $V(y) \geq 0$ for all y
- A feasible O is *Pareto optimal* if there is no other feasible O' such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

Proposition (2)

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

Implementability for Identical Workers, ctd



Implementability for Identical Workers

Proposition (2)

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

Proof sketch:

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

Worker Coordination Problem

- Back to general Y

Worker 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:

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

Worker Coordination Problem, ctd

- Coordination problem, intuitively:
  - a worker keeps his schedule open by rejecting low-value jobs to increase his individual chances of getting high-value jobs
  - as a result in eqm, workers 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 worker makes himself available and decreases the other workers' chances of getting subsequent jobs
- Fundamentally, workers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained

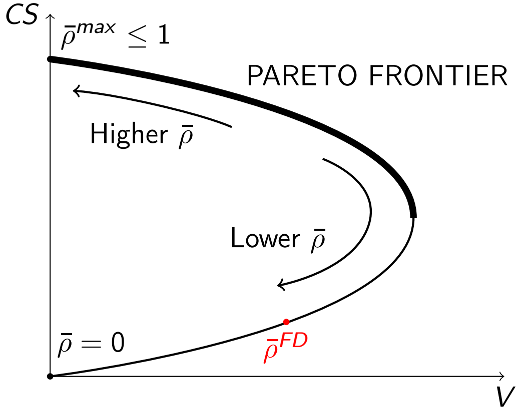
Proof Sketch

For the case of identical workers

1. X convex, π cts in x –> $V > 0$
2. Individually:
   - Worker'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 $\pi \geq 0$

Worker Coordination Problem, Identical Workers



Implement a Pareto improvement with heterogeneous workers?

- Generally not -> next section

Linear Payoff Environment

- $X = [0, 1]$
  - e.g. job difficulty
- $Y = [0, \bar{y}]$
  - e.g. worker 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. workers are heterogeneous
2. worker availability is endogenous
3. disclosure affects workers' 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 Worker 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 workers 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 worker 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 $\xi^* < 0$.

Worker 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, worker's optimal strategy has a cutoff form. Furthermore, worker 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,

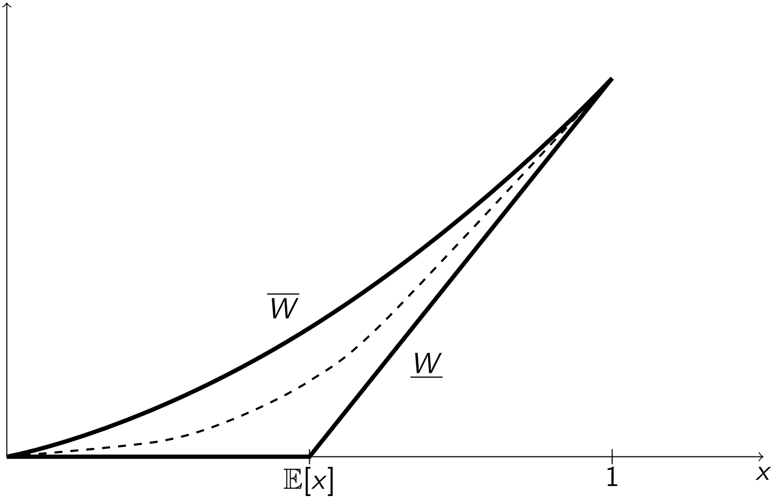
$$\underline{W}(z) := \max\{0, z - \mathbb{E}[x]\}.$$

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:

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

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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 Worker 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 workers
  - heterogeneous workers but high buyer-to-worker ratio
  - heterogeneous workers 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 workers

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 worker who is about to transact with another searcher
3. Stale vacancy: worker did not update his status to "unavailable"

Burdett et al. 2001, Kircher 2009, Arnosti et al. 2014: mis-coordination
My paper: screening

Back

Impatient Workers

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

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

Back