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

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Decentralized Matching Markets

In *matching markets*, both buyers and sellers have preferences over the other side

- labor market
- rental housing
- transportation
- dating
- coaching, massage
- kidney exchange
- etc.

In a *decentralized* matching market, participants on one side search for suitable options on the other side

Matching Frictions

that pertain to heterogeneity of preferences

Two sides: buyers and workers

Cross-side Search Externality

When participants on the one side shop for better options, they waste the other side's time and/or search effort

Same-side Search Externality

By remaining unmatched, a worker creates competition to the other workers for better buyers

Result: excessive search

Congestion

Examples

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- Airbnb hosts reject 20% of guest inquiries due to bad fit (Fradkin 2015)
- If Uber drivers were allowed to cherry pick rides, passengers would have to wait longer
- On Upwork (labor platform for freelancers), workers prefer receiving many inquiries from employers, while employers prefer to find a worker in a single interaction session (Horton 2015)

Platform Design

Platform's value proposition is to facilitate matching

Policies to overcome search externalities in heterogeneous environment:

- structured search
    - lower search costs
    - limit search
    - recommendation system
- information structure
- flexible pricing

Information Disclosure

- We know that information disclosure facilitates trade and exchange (Blackwell 1953, Akerlof 1970, Myerson-Saterthwaite 1983, Lewis 2011)
- However, information availability increases perceived diversity of options -> induces more shopping -> matches take longer to consummate
- Other problems with info disclosure: excessive signaling (Hoppe et al. 2009), failure to share risk (Hirschleifer 1971)

Research Question

Question

What should be information disclosure policy in matching markets?

Examples

- Passenger attributes on Uber: show/not show destination, gender
- Airbnb: what information should be elicited from guests to be shown to hosts? Gender, age, day schedule?
- Star ratings: half-star step/10th-of-star step

Conceptual Preview of Results

Important Observation #1

In decenetralized matching markets, search for better options is excessive owing to negative same-side and cross-side search externalities

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In decenetralized matching markets, search for better options is excessive owing to negative same-side and cross-side search externalities

Important Observation #2

Platform's policy of *coarse* revelation of buyer information alleviates the workers' excessive search problem and improves efficiency of the marketplace

Preview of Results

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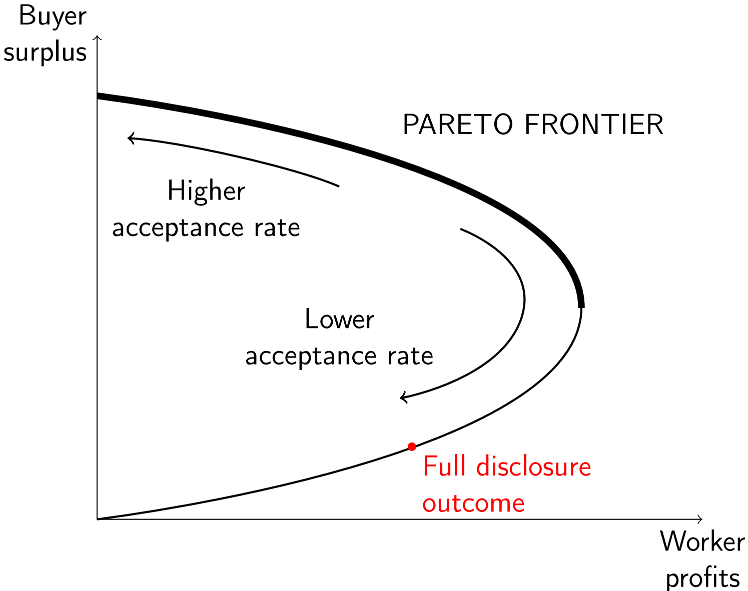
2. Identical workers -> information disclosure policies implement any point on the Pareto frontier in axes of buyer surplus and worker surplus
3. Unmediated market -> market outcome is Pareto dominated due to *scheduling externality*
   - Unmediated = full disclosure

Preview of Results



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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

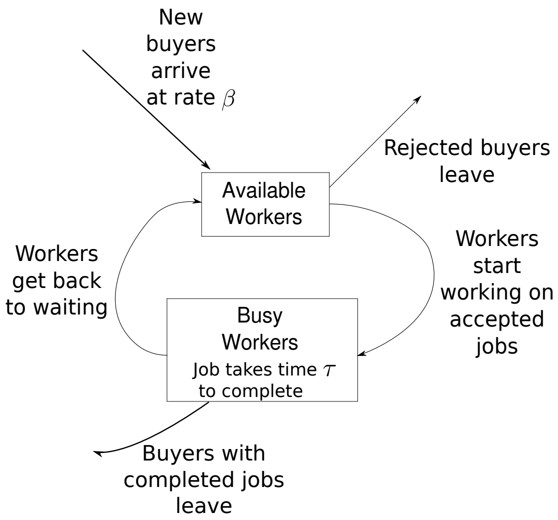
Matching in Labor: Becker 1973, Shimer-Smith 2000, Kircher 2009

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
Type	$x \in X \subset \mathbb{R}^n$	$y \in Y \subset \mathbb{R}^m$
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

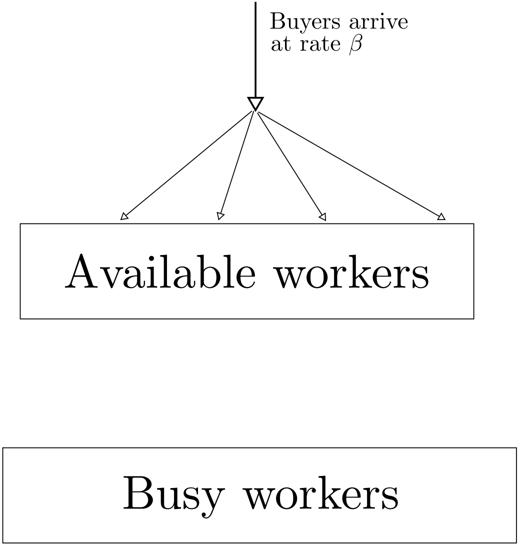
- $S = \Delta(X)$ set of all possible signals
  - $s \in S$ is posterior distribution of x
- $\mu \in \Delta(S)$ disclosure policy
  = distribution of posteriors
- Platform does not elicit y

Steady State of the Matching Process

State of the matching system:

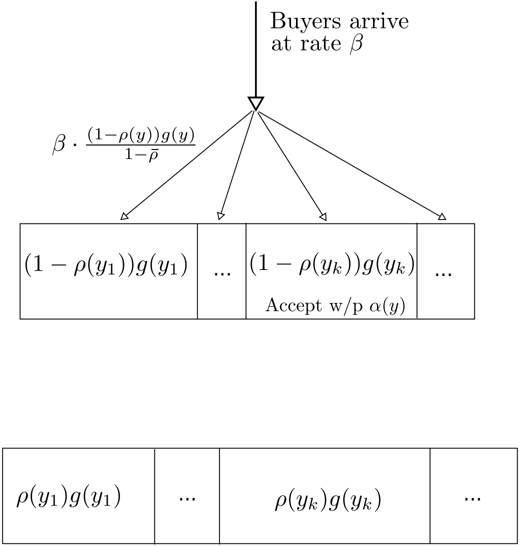
1. $\alpha(y) \in [0, 1]$ *acceptance rate*
   - fraction of jobs accepted by available type-y worker, $\alpha(y) = \mu(s \text{ is accepted by } y | y \text{ is available})$
2. $\rho(y) \in [0, 1]$ fraction of time type-y worker is busy
   - *utilization rate* of type-y workers
   - Worker's constrained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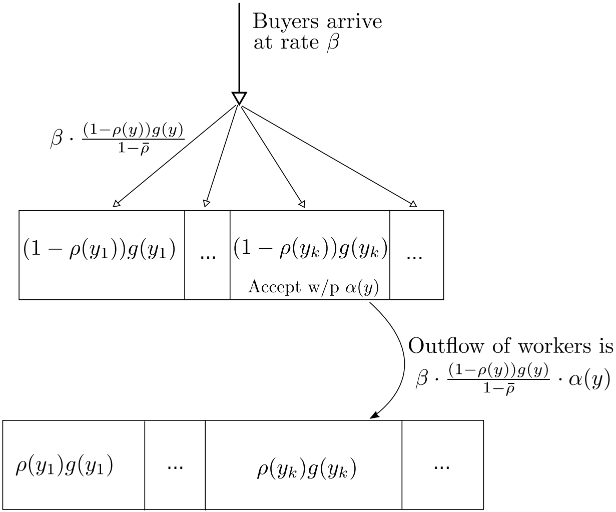

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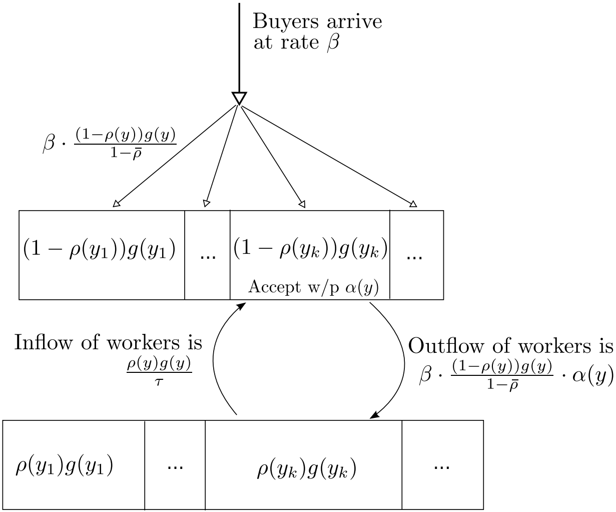

Steady State of the Matching Process

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

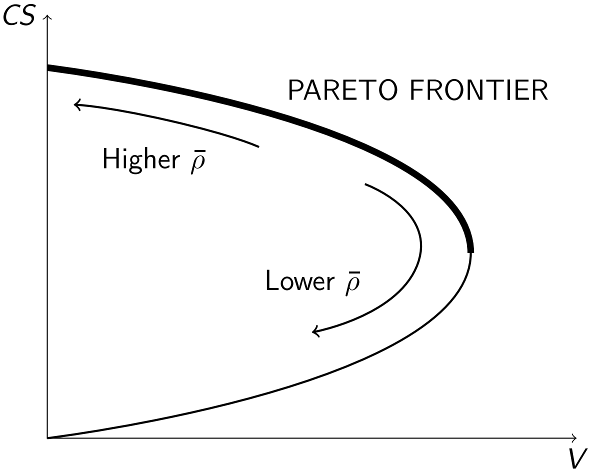
- Market outcome $O = (\{V(y)\}, CS)$ is a combination of worker profits and consumer surplus
- Market outcome is *feasible* if
  1. there are acceptance strategies for workers that generate it, and
  2. $V(y) \geq 0$ for all y
- A feasible O is *Pareto optimal* if there is no other feasible O' such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



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Proof sketch:

1. 1 worker type, 2 actions -> $X = X_{acc} \cup X_{rej}$ -> binary signaling structure is sufficient
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

Why Information Coarsening Trades off Buyer and Worker Surplus

Intuition for static case with 1 worker

Based on standard information disclosure (Aumann-Maschler 1995, Kamenica-Gentzkow 2011)

-\$50	...	-\$1	\$0	\$1	\$2	...	\$50

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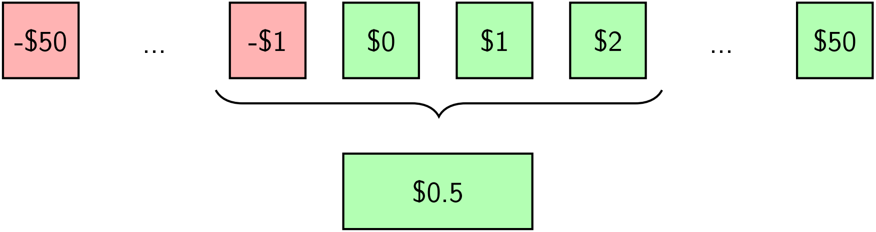


Worker Coordination Problem

- 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

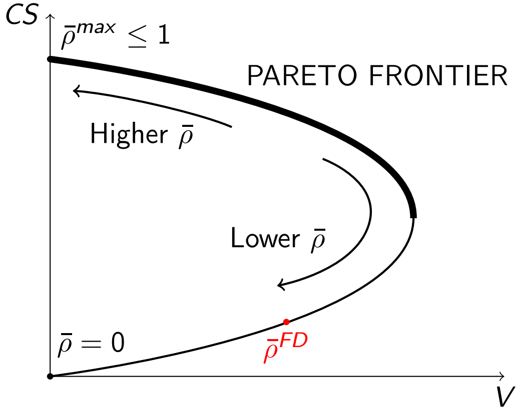
- Fundamentally, workers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained

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:

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

- Pareto efficient outcome

The problem is not trivial because:

1. workers are heterogeneous
2. disclosure affects workers' option value
3. disclosure alters equilibrium value of arrival rate β_A

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 $x > x^*$

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,

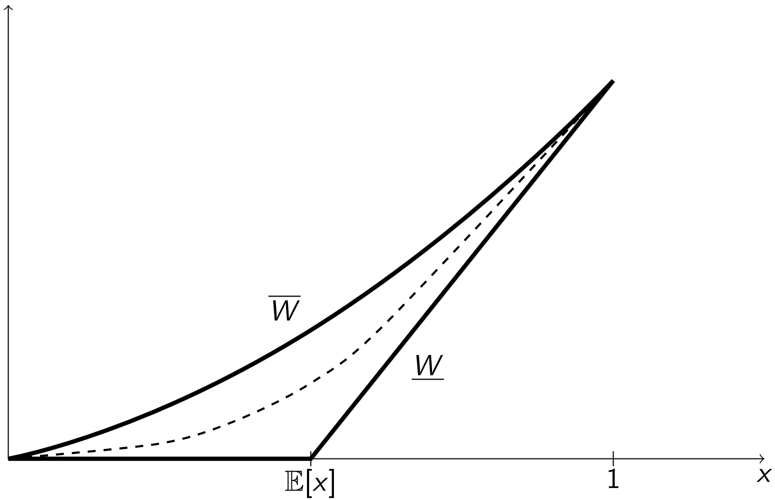
$$\underline{W}(z) := \max\{0, z - \mathbb{E}[x]\}.$$

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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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
    - workers compete for the best jobs by ignoring other valuable jobs
- Full disclosure -> workers are under-utilized and welfare is lost
- Information coarsening can be Pareto improving and increase benefits of participation on both sides of the market
    - when workers are homogenous
    - there are more high-skill workers than low-skill workers
    - higher buyer-to-worker ratio
    - capacity constraints are more severe

Further Directions

- Optimal pricing and disclosure to maximize revenue
- 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