Ignorance is Strength: Improving Performance of Peer-to-peer Markets by Limiting Information

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Information Disclosure in Peer-to-peer Markets

- How does information disclosure in peer-to-peer markets affect benefits from participation on either side?

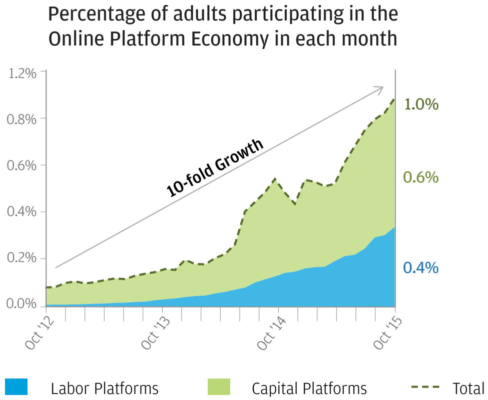
- Standard economics literature on two-sided markets (Rochet-Tirole 2006, Weyl 2010, Armstrong 2006) develops price theory for two-sided markets where cross-side effects are held fixed
- The theory applies well to product platforms such as video game platforms and credit card companies
- In peer-to-peer markets, such as Airbnb, other design choices become important: reputation systems, flexible pricing, search, information structure, etc

Relevant Features of Peer-to-Peer Markets

As appear in my model

- Decentralized matching
- Workers and buyers have preferences over the other side
- Worker capacities are limited
- Workers have discretion over what matches to accept

Digital Marketplaces are Increasingly Relevant



- Airbnb now lists more rooms than any hotel chain
- There are more Uber drivers than taxi drivers in US

Capacity Utilization

- Important observation #1: Capacity utilization affects welfare on both sides of the market
  - Capacity = maximal worker output per unit of time
  - *Capacity utilization rate* = proportion of capacity that is actually realized

- Workers face a tradeoff between higher capacity utilization and higher match quality
- Buyers benefit from higher capacity utilization due to matching frictions
  - higher capacity utilization <-> higher acceptance rate

- In peer-to-peer markets, the platform does not have direct control over capacity utilization, and the workers resolve utilization-quality tradeoff individually

Information Disclosure

- Key observation #2: availability of information about buyers affects capacity utilization
- So, information disclosure can be used to balance the sides of the market

Example: Uber

- Capacity utilization — fraction of time on the road workers actually giving rides
- Drivers like to be busy but also want to avoid too long rides or remote neighborhoods
  - driver utility is hump-shaped in utilization
- Passengers like high acceptance rates

Preview of Results

1. Identical workers -> information disclosure implements any point on the Pareto frontier in axes of buyer surplus and worker surplus

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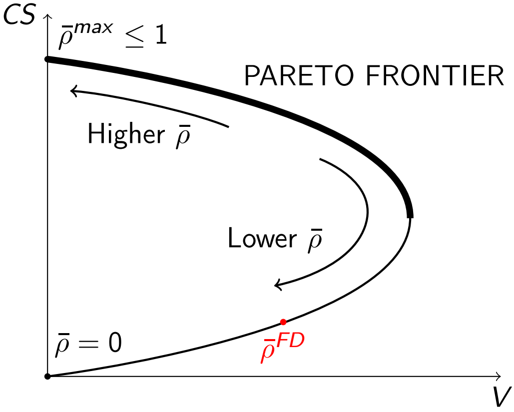


Preview of Results

1. Identical workers -> information disclosure implements any point on the Pareto frontier in axes of buyer surplus and worker surplus

2. Un-mediated market -> market outcome is Pareto dominated due to *scheduling externality*

3. Optimal disclosure in linear cost environment to maximize utilization. Information coarsening if
   - there are fewer low-skill workers than high-skill workers
   - higher buyer-to-worker ratio
   - capacity constraints are more severe

Related Literature

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

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

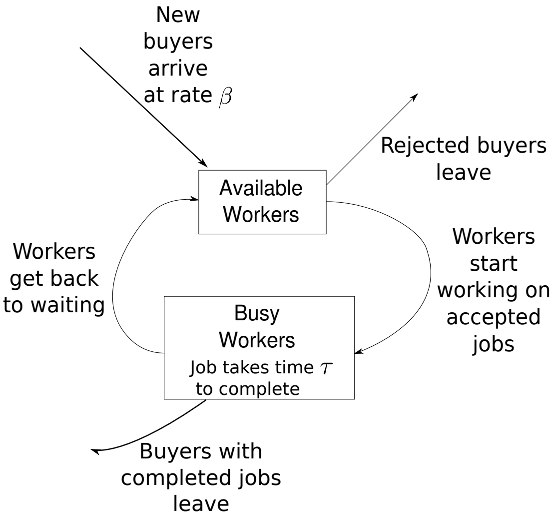
Matching in Labor: Becker 1973, Shimer-Smith 2000, Kircher 2009

Market Design: Milgrom 2010, Akbarpour et al. 2016

Peer-to-peer markets: Fradkin 2015, Horton 2015

Platforms in OR: Ashlagi et al. 2013, 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

Assumption (Random Assignment)

Buyers are assigned uniformly at random to the available workers.

- Search is costly:
  - job accepted -> buyer stays until the job is completed
  - rejected -> leave

Heterogeneity and Payoffs

	Buyers	Workers
Type	$x \in X$	$y \in Y$
Cdf, pdf	F, f	G, g
1-match net payoff	$u(x, y) - p_y$	$p_y - C(x, y)$

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

Intermediary: Information Disclosure

Information structure:

- Platform observes x but not y
  - Assume: platform does not elicit 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
  - s.t. average posterior = prior, $\int_S s\mu(ds) = f$
  - public disclosure
- default is full disclosure

Worker Repeated Search Problem, ctd

- When available, buyers arrive at Poisson rate β_A
  - β_A is endogenous b/c mass of available workers is endogenous
- $V(y)$ per-moment value of being available, in the optimum
- Every time a job with signal s arrives, worker y gets $\pi(s, y)$
  - $\pi(s, y)$ includes option value of waiting
- $C(y, s) := \int_X C(y, x)s(dx)$ expected cost after signal s for worker y
- Worker optimization problem

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

- No discounting

Impatient Workers

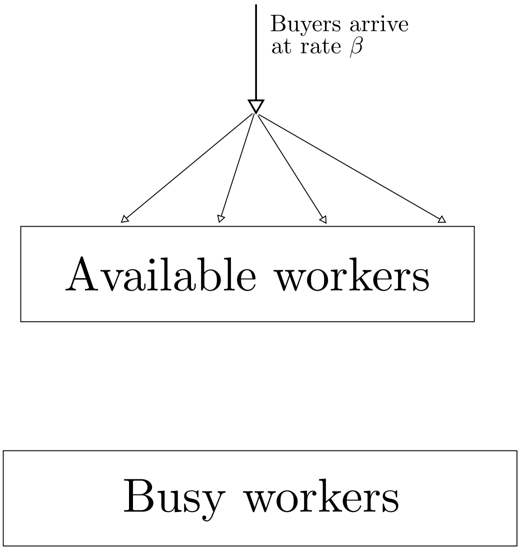
State of the Matching System

- Worker's constrained resource is time
  - capacity $= 1$

State of the matching system:

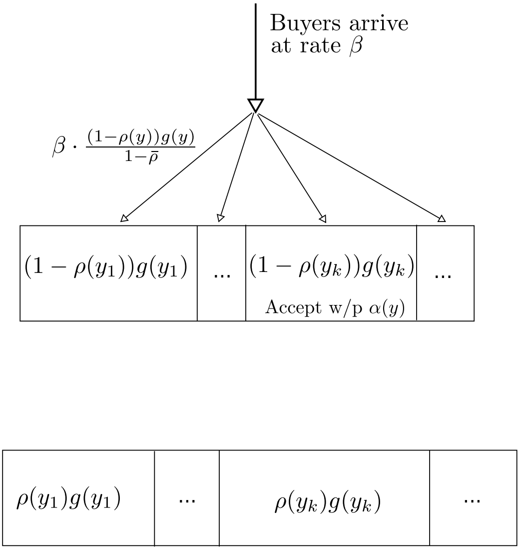
1. $\alpha(y) \in [0, 1]$ *acceptance rate*
   - fraction of jobs accepted by available type-y worker, $\alpha(y) = \mu(s \text{ is accepted by } y | y \text{ is available})$
2. $\rho(y) \in [0, 1]$ capacity utilization rate of type-y workers
   - fraction of time type-y worker is busy

Steady State



Steady State

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



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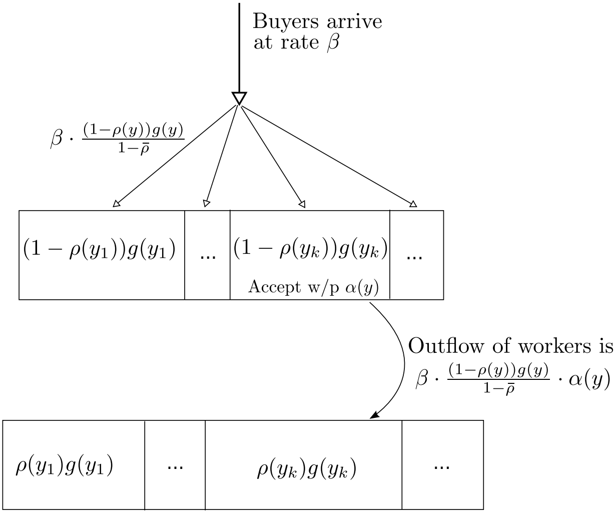

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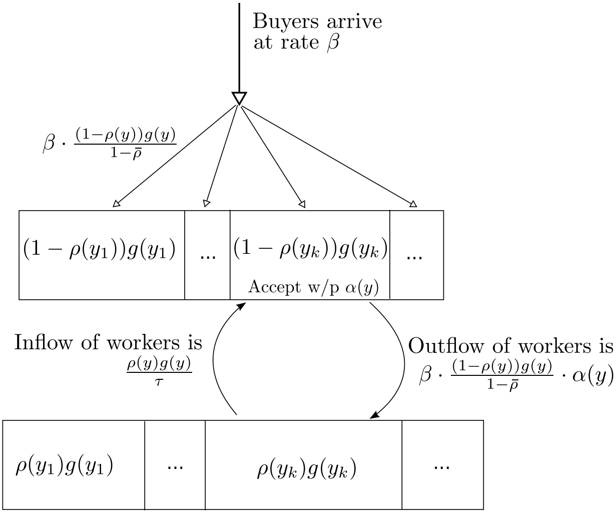

Steady State

In a steady state, the flows to and from the pool of busy workers are equal, for each worker type:

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

Solution

Average utilization $\bar{\rho}$ is a solution to

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

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

Steady-State Equilibrium

$((\alpha(y))_{y \in Y}, \bar{\rho})$ is a *steady-state equilibrium* if

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

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We make the following assumption to make the exposition easier.

Assumption (No Excess Demand)

Collectively, it is physically possible for workers to complete every buyer job: $\beta\tau < 1$.

Proposition (1)

Steady-state equilibrium exists and is unique.

Market Design: Information Disclosure

Equilibrium $(\alpha(.), \bar{\rho})$ is a function of disclosure policy μ and prices

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
  - prices fixed

Implementability for Identical Workers

Proposition (2)

Suppose workers are identical. Then any point on the Pareto frontier can be implemented by a disclosure policy.

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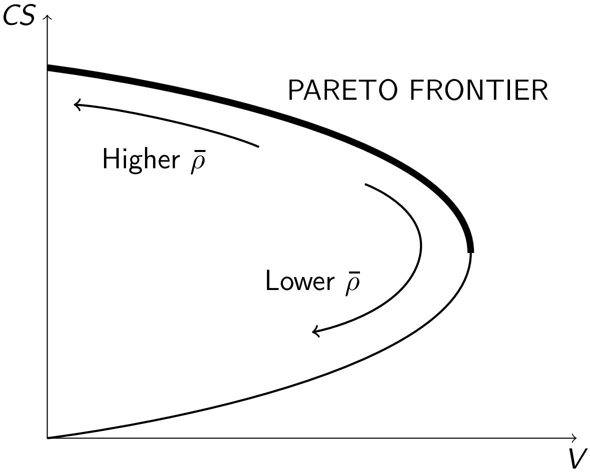
Proof sketch:

1. Revelation Principle -> binary signaling structure
2. With binary signaling structure, dynamic problem reduces to static problem
3. By a standard argument (Auman-Maschler 1995, Kamenica-Gentzkow 2011), obedience constraint -> $\alpha \in [\alpha^{min}, \alpha^{max}]$ is implementable
4. Worker profit is hump shaped in α, consumer surplus in increasing in α

Implementability for Identical Workers, ctd



Worker Coordination Problem

- Back to general Y

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- Denote worker-y's acceptance strategy by $\sigma(s, y) \colon S \to [0, 1]$
- $V^\sigma(y)$, $\rho^\sigma(y)$, CS^σ denote steady-state profits, utilization rates and consumer surplus when strategy profile σ is played

Proposition (3)

Suppose $\min_x C(y, x) < p_y < \max_x C(y, x)$ *for all* y. *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

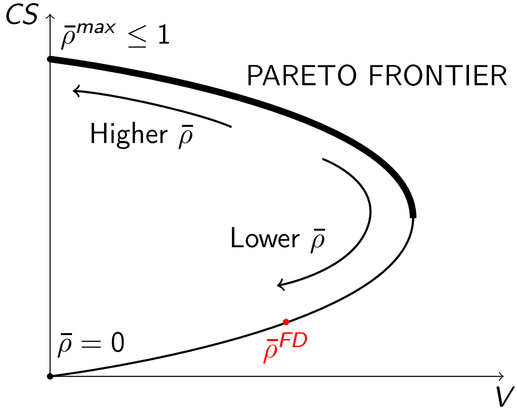
- Coordination problem, intuitively:
  - a worker keeps his schedule open by rejecting low-value jobs to increase his individual chances of getting high-value jobs
  - collectively, this behavior is suboptimal because all profitable jobs have to be completed
    (feasible by No Excess Demand assumption)
- *Scheduling externality*: by rejecting a job a worker decreases the other workers' chances of getting consequent jobs.
- Fundamentally, workers jointly are not capacity constrained (in time) while individually, they *are* capacity constrained.

Proof Sketch

For the case of identical workers

- Individually:
  - Worker's option value of rejecting is
    $$\tau V > 0$$
  - in eqm, accepted jobs have costs $c \leq p - \tau V$
  - profitable jobs have $c \leq p$
  - so, some profitable jobs are rejected
- Collectively:
  - no capacity constraint in aggregate => zero option value of rejecting
  - accepted jobs have $c \leq p$

Worker Coordination Problem, Identical Workers



Implement a Pareto improvement with heterogeneous workers?

- Generally not -> next section

Linear Cost Environment

- $X = [0, 1]$
  - e.g. job difficulty
- $Y = [0, 1]$
  - e.g. worker skill
- $C(x, y) = x - y$
- Platform does not elicit y

Maximal Capacity Utilization

What is the optimal disclosure policy to maximize utilization?

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

The problem is not trivial because:

1. workers are heterogenous
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 concave, then full disclosure is optimal
- If G is convex, no disclosure is optimal.
- If G is linear, 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

Full Disclosure is Optimal?

Proposition (4: Necessary condition for optimality of full disclosure)

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

$$g'(1)/g(1) > \xi^*,$$

then full disclosure is sub-optimal. Furthermore, if

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

for some $\chi^* \in (1/2, 1)$, then $\xi^* < 0$.

Full Disclosure is Optimal?

Proposition (4: Necessary condition for optimality of full disclosure)

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Proposition (5: 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.

No Disclosure is Optimal?

Proposition (6: 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.

Worker Optimization Problem

Lemma (1)

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

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

where

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

is the option value function, F^{μ} is the distribution of posterior means of x.

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,

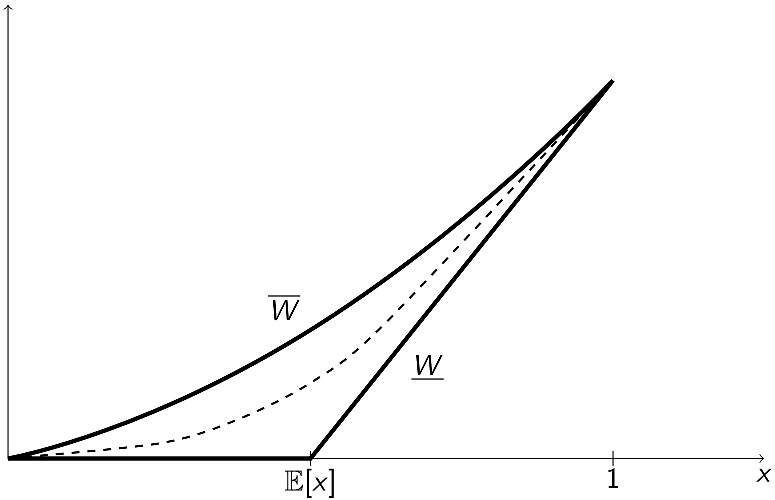
$$\underline{W}(z) := \max\{0, z - \mathbb{E}[x]\}.$$

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 $\delta W(1) < 0$

Conclusion

Summary

- In peer-to-peer markets, capacity utilization affects welfare on both sides of the market
- Full disclosure -> workers are under-utilized
- 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

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