Matching job applicants to vacancies: An empirical model of multi-stage hiring

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Motivation

- In many large firms, the hiring process has multiple stages.
  - *Some candidates are eliminated at each stage* and the firm does not learn about the full skill set of each applicant.
- There is a growing literature on *structural estimation of search and matching models*, which we adapt to this context.
- We aim to understand the mechanism used to select the successful candidate from the pool of applicants.
- Why is the *hiring process treated like a black box* in most past work?
  1. Data limitations: need data on applications, who is interviewed, and who is hired.
  2. Computational challenges: when you choose the optimal set of candidates to interview, the number of possible combinations can be quite large.

Motivation
Aim of paper (work in progress)

Display some new empirical regularities in job search and matching with a unique data set taken from a large firm showing:

- *Search activities* by employees.
- *Hiring* procedure that culls applicants in stages.
- *Job spell durations* and *promotions.*

Develop a dynamic game:

- With a *multistage selection process* endogenizing consideration sets.
- The game rationalizes an apparent *lack of teamwork* within firms.
- Equilibrium wages depend on the competition faced by the successful candidate.

Estimate model and use it to:

- How does *multistage choice* affect outcomes?
- Predict effects of *imposing regulations* on hiring.

Literature review

- Empirical work using observed search intensities. [Bang and Wang (2024), Faberman, Mueller, Sahin, and Topa (2022)]

  We directly observe the frequency each candidate submits applications, and use this to model a worker's search intensity.

- Recent literature on the matching process studies how firms make interview decisions. [Gottardi, Lester, Michaels, and Wolthoff (2024), Vohra and Yoder (2024)]

  We develop and estimate a model of multistage choice to learn how interactions within the firm affect outcomes.

- Racial and gender wage differences. [Bertrand and Mullainathan (2004), Shukla (2024), Russo and van Ommermen (1998), Babcock and Laschever (2007), Altonji and Blank (1999), O'Neill (1970), Neal and Johnson (1996), Carneiro, Heckman, and Masterov (2005), Golan, James, and Sanders (2024), Blau and Kahn (2017), Gayle and Golan (2023), Gayle, Golan, and Miller (2023), Xiao (2021)]

  We can analyze the role the search and matching process plays in these differences.

- Choice of consideration sets. [Barseghyan, Coughlin, Molinari, and Teitelbaum (2023), Coughlin (2023)]

  We directly observe the consideration (interview) sets.

Data
Description of primary data set

- Primary dataset provided by a *large anonymous firm* with about 65,000 workers:
  - Observe data in a 5 year period in the first decade of the 21st century.
  - See all job vacancies, employees, job applicants, and hiring details.
- For each *job vacancy*, we see a brief job description including its division and salary range. We use the job descriptions to create *occupations*.
- For each *job application*, we observe whether the candidate met minimal qualifications, voluntarily *withdrew the application*, was *interviewed*, and was *offered* (and accepted) the job.
- For each *employee* we observe:
  - Demographics (race, gender, age, education, work experience).
  - All job applications and outcomes in this 5 year time period.
- This dataset is supplemented with wage information for up to 20 years for all the firm's employees.

Data
Descriptive statistics on applications

Applications per candidate	4.88
Applications per job	37.02
Qualified and interested applications per job	20.64
Interviewed candidates per job	4.93
Applications with no experience	0.92
Number of applicants	39,341
Number of vacancies	3,330

Worker side descriptives Firm side descriptives

Model overview
Worker side

- Utility depends on wages and the non-pecuniary benefits of a job.
- Workers make decisions to maximize expected lifetime utility.
- Employment opportunities arrive at some rate for each worker (employed or unemployed).
    - Workers decide whether or not to pursue the employment opportunity (which we define as completing the application).
    - They pay a cost for each completed application.
- If a worker completes the application, they receive a job offer with some probability.
    - We assume all offers are accepted.
   - When a worker moves to a new job, they pay a relocation cost.
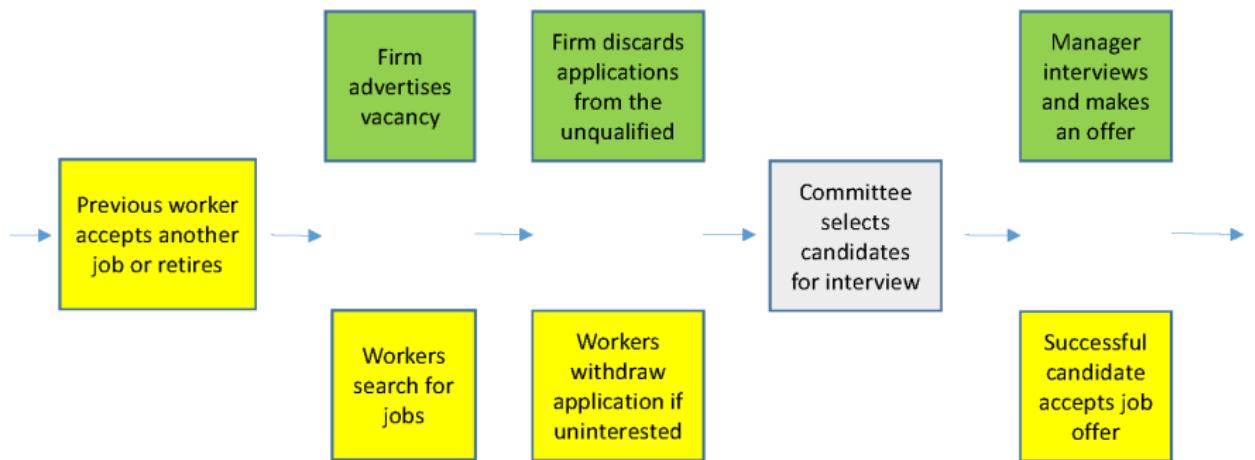
Model overview
Firm side

- For each posted vacancy, the firm sees the pool of completed applications.
- The hiring proceeds as follows:
  1. Unqualified applicants are discarded (deterministic process).
  2. The *interview committee* chooses a *set* of candidates to interview. The interview committee chooses the interview set that maximizes their expected utility from the hired candidate. Their utility depends on:
     - The expected value to the manager from the hired candidate.
     - The committee's *divergent preferences* over characteristics.
     - An idiosyncratic term only observed by the interview committee.
  3. The *manager* interviews the candidates, thereby learning each worker's productivity.
  4. The manager offers the job to the candidate that provides the highest value.

Model

Flow chart describing hiring process

Firm advertises vacancy

Firm discards applications from the unqualified

Manager interviews and makes an offer

Previous worker accepts another job or retires

Committee selects candidates for interview

Workers search for jobs

Workers withdraw application if uninterested

Successful candidate accepts job offer
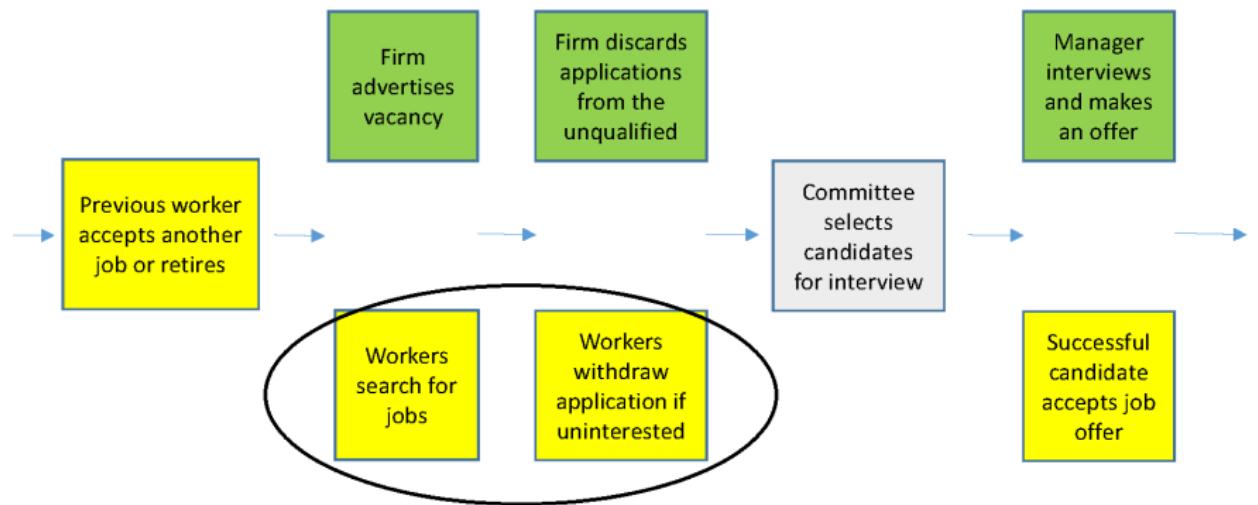
Model

Flow chart describing hiring process

Model
Worker's application decisions

- After seeing a job opportunity, a worker decides whether or not to complete the application.
- We compute the value of not completing the application, V_0.
- V_0 depends on:
  - Wages w and non pecuniary benefits u of current job.
  - Continuous time discount rate δ.
  - Rate of arrival of new job opportunities ρ.
  - Ex-ante value V of being in a job with flow utility $u + w$.

$$V_0 = \frac{1}{\delta} \left[w + u + E\left[\exp\left(-\delta\rho \right) \right] \left(\delta V - w - u \right) \right]$$

Lifetime optimization problem

Model
Worker's application decisions

The value of completing a job application V_1 additionally depends on:
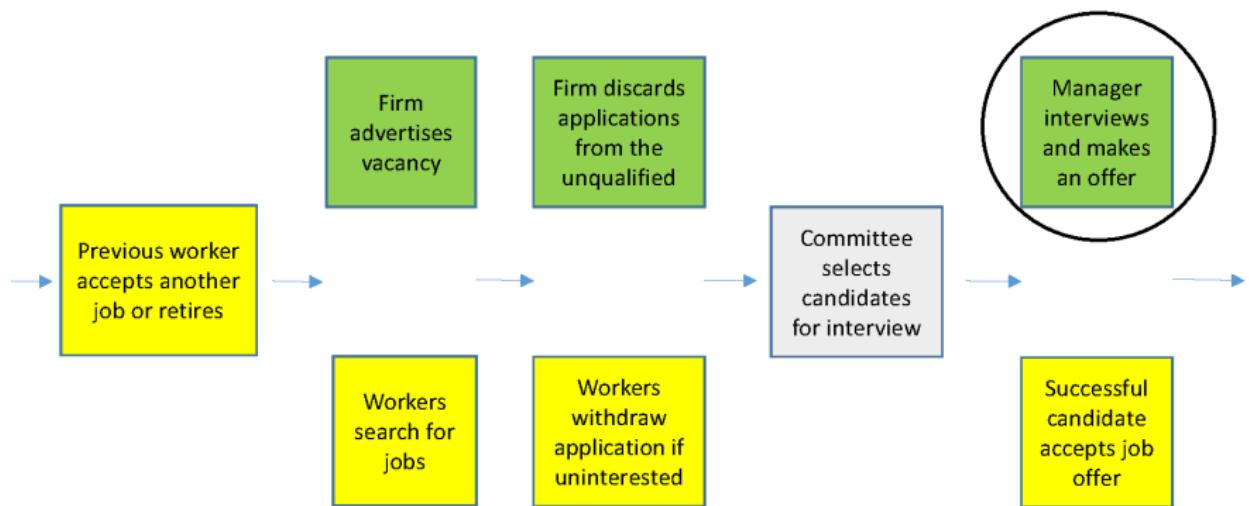
- Probability of receiving a job offer if you complete the application ϕ.
- Value $\widehat{V}$ of being in a new job with flow benefit $\widehat{w} + \widehat{u}$.
- Relocation cost if you move to new job, $\widehat{\epsilon}$ (which is learned after you make the submission decision).

$$V_1 = (1 - \phi) V_0 + \frac{\phi}{\delta} E \left[\widehat{w} + \widehat{u} - \delta\widehat{\epsilon} + E \left[\exp\left(-\delta\rho\right) \right] \left(\delta\widehat{V} - \widehat{w} - \widehat{u} \right) \right]$$

- Define ξ as the cost of submitting an application.
- Worker completes an application if and only if $\xi \leq V_1 - V_0$.

Model
Flow chart describing hiring process

The manager's value from hiring worker a is:

$$M\left(\pi_a, w_a\right) = \pi_a - w_a + E\left[\exp\left(-\delta\tau_a\right)\right]\left[M_0 - \left(\pi_a - w_a\right)\right]$$

- π_a is the productivity of a.
- w_a is the wage rate.
- τ_a is the duration worker a stays at the job.
- M_0 is the value to the manager from filling the vacancy.
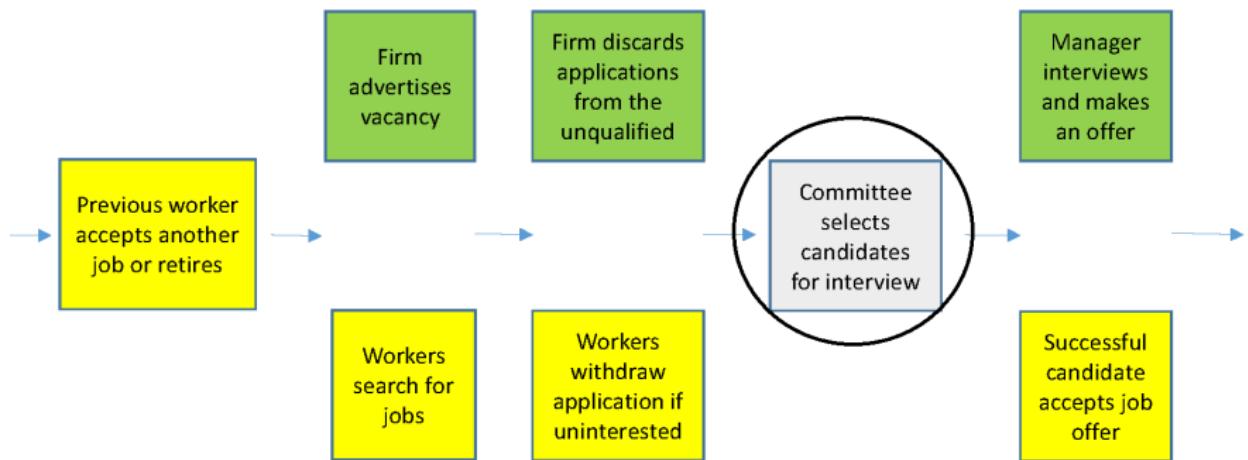
- The manager interviews a set of candidates, and chooses whom to hire.
- We model the manager's hiring decision similar to a second price auction.
- Each interviewed worker c announces their reservation wage $\overline{w}_c$.
- Manager ranks applicants by the profitability index $M(\pi_c, \overline{w}_c)$.
- Suppose a is the highest ranked and b is the second highest ranked.
- Manager offers a the job at wage $\widehat{w}_a$, which gives the firm the same value as they would have received if b was hired at his reservation wage. Example
- The equilibrium wage is given by $M(\pi_a, \widehat{w}_a) = M(\pi_b, \overline{w}_b)$:

$$\widehat{w}_a = \overline{w}_b + \pi_a - \pi_b + \frac{E\left[\exp\left(-\delta\tau_a\right)\right] - E\left[\exp\left(-\delta\tau_b\right)\right]}{1 - E\left[\exp\left(-\delta\tau_a\right)\right]}\left(\overline{w}_b - \pi_b + \delta M_0\right)$$

Reservation wages

Model

Flow chart describing hiring process

- The interview committee chooses the consideration set $\mathbb{C}$ that maximizes their expected utility of the hired candidate.
- Their utility from a hired candidate comes from the value to the manager M and their divergent preferences L_c.
- They face uncertainty over π_c and $\overline{w}_c$ for each candidate c, which follow the distribution $F_c(\pi_c, \overline{w}_c)$.
- Pay a cost λ for each interview.
- The committee chooses a set $\mathbb{C}$ to maximize:

$$\int \sum_{(c_1, c_2) \in \mathbb{C}} \mathbf{1}\{(c_1, c_2) = (a, b)\} \left[L_{c_1} + M\left(\pi_{c_1}, \overline{w}_{c_2}\right) \right] \prod_{c \in \mathbb{C}} dF_c\left(\pi_c, \overline{w}_c\right) - \lambda \left|\mathbb{C}\right|$$

- When making this decision, they are comparing a very large number of possible consideration sets

- Suppose the productivity of candidates are independent and there are no divergent preferences ($L_c = 0$).
- Denote the set of applicants as $\mathbb{B}$. Also assume there exists an ordering of candidates denoted by $\{c\}_{c=1}^{B}$ such that

$$\int \int_{M(\pi_c, \overline{w}_c) \leq M} dF_c\left(\pi_c, \overline{w}_c\right) \leq \int \int_{M(\pi_{c+1}, \overline{w}_{c+1}) \leq M} dF_{c+1}\left(\pi_{c+1}, \overline{w}_{c+1}\right)$$

- Let $\mathbb{C}_N = \{c\}_{c=1}^{N}$
- Denote $\overline{L}\left(\mathbb{C}_N\right)$ as the expected surplus to the firm from an interview set of size N.
- The interview size N is the unique solution to

$$\overline{L}\left(\mathbb{C}_N\right) \geq \max\left\{\overline{L}\left(\mathbb{C}_{N-1}\right) + \lambda, \overline{L}\left(\mathbb{C}_{N+1}\right) - \lambda\right\}$$

Consideration sets
Relaxing independence

- Suppose there are 4 types of applicants.
- When the interview committee makes a decision, they do not know the exact task of the vacancy. There are 3 possible tasks, each equally likely.
- $\pi_k = (\pi_{k1}, \pi_{k2}, \pi_{k3})$ denotes the skill vector for type $k \in \{1, \ldots, 4\}$
- Assume a static model, with no divergent preferences, and firm maximizes the productivity of hired worker
- Let $\mathbb{B}_N$ maximize common preferences for choosing $\mathbb{C}$ subject to $B \leq N$:

$$
\pi_k = \left\{ \begin{array}{l} (3/4, 3/4, 0) \text{ if } k = 1. \\ (0, 0, 3/4) \text{ if } k = 2. \\ (0, 1, 0) \text{ if } k = 3. \\ (1, 0, 0) \text{ if } k = 4. \end{array} \right.
\qquad
\mathbb{B}^N = \left\{ \begin{array}{l} \{2, 0, 0, 0\} \text{ if } N = 2. \\ \{1, 0, 1, 1\} \text{ if } N = 3. \\ \{0, 0, 2, 2\} \text{ if } N = 4. \\ \{1, 2, 1, 1\} \text{ if } N = 5. \\ \{0, 2, 2, 2\} \text{ if } N = 6. \end{array} \right.
$$
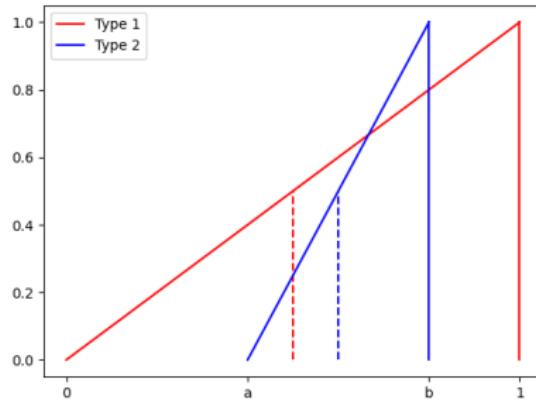
Consideration sets
Divergent preferences

- Suppose there are 3 candidates $k \in \{1, 2, 3\}$.
- The committee's valuations are independently drawn from the uniform distribution with support $[\underline{\pi}_k, 1]$ where $0 = \underline{\pi}_1 \leq \underline{\pi}_2 \leq \underline{\pi}_3$.
- The firm values the second applicant at 1 and the other 2 the same as the committee.
- The committee could choose the first and third candidates even though applicants 2 and 3 have the highest expected productivity.
    - This is because they know the firm would choose candidate 2 if he is in the consideration set.

- Suppose the committee's utility from each type is independently drawn from the following distributions.

- When a small number of candidates is interviewed, there are 0 type 1 candidates (mean effect dominates).
- When a large number of candidates is interviewed, there are 0 type 2 candidates (variance effect dominates).

Empirical Methods
Parameterizing the worker's preferences

- The applicant pool for the nth vacancy is denoted by $\mathbb{A}_n$.
- $a_n \in \mathbb{A}_n$ knows (x_{an}, ζ_{an}) at the time a new job opportunity n arrives:
  - x_{an} is a vector of characteristics relating to the job and the applicant.
  - ζ_{an} is the submission cost, which follows the normal distribution with mean 0.
  - $u_{an} = x_{an}\gamma$ are the preferences of a_n for current job
  - $\widehat{u}_{an} = \widehat{x}_{an}\gamma$ are he preferences for n^{th} job opportunity
  - ϵ_{an} is the relocation cost, which follows the normal distribution

- The firm evaluates candidates a_n on the basis of their productivity

$$\pi_{an} = x_{an}\alpha + \zeta_{an}$$

  - ζ_{an} is an iid normal random variable with mean 0 and standard deviation σ_ζ
  - σ_ζ measures the importance of information learned at the interview

- The committee's deviation from the manager's preferences are given by

$$L_{an} = x_{an}\beta + \eta_{an}$$

  - η_{an} is iid normal with mean 0 and standard deviation σ_η.

- 3 features differentiate committee's preferences from managers's:
  - Committee cares about η_{an} but the manager does not.
  - Committee values x_{an} differently from the firm when $\beta \neq 0$.
  - Manager knows ζ_{an} when making decisions but the committee does not.

Empirical Methods
Estimation strategy

Estimation is split into distinct parts, joined only by bootstrapping the standard errors:

1. Stage 1: Estimate ancillary parameters and simulate unobservables.
2. Stage 2: Estimate preference parameters of applicants and the productivity parameters of the manager using an iterative process.
3. Stage 3: Estimate committee's preferences from their choice of the consideration set, a computationally intensive exercise.
   - For up to 7 interviewed candidates, we search globally.
   - For 8-11 candidates, we use the marginal condition from the theorem.

Empirical Methods
Stage 1: Ancillary parameters and simulations

- The **nonparametrically identified incidental parameters** are:
    - Probability of completing application

    $$p_{an} = \Pr\left[a_n \text{ completes application} \,|\, a_n \in \mathbb{A}_n, x_{an}\right]$$

    - Probability of being offered position

    $$\phi_{an} = \Pr\left[a_n \text{ offered position} \,|\, x_{an}, a_n \text{ completes application}\right]$$

    - Discount on waiting for next employment opportunity

    $$E\left[e^{-\delta \rho_{an}} \,|\, x_{an}\right]$$

    - Discount on spell length.

    $$E\left[e^{-\delta \tau_{an}} \,|\, x_{an}\right]$$

- The **simulated unobserved variables** are:
    - $\epsilon_{an}^{(s)}$ relocation shock for the applicant a to vacancy n
    - $\zeta_{an}^{(s)}$ and $\eta_{an}^{(s)}$, productivity shock and committee preference factor

We use an iterative procedure to estimate the productivity terms and the non-pecuniary preferences of candidates

1. Start with a guess for $\widehat{\epsilon}_n$, which is the expected value of the relocation cost conditional on being offered the position.

2. Estimate the non-pecuniary benefits of a given position using the candidate's decisions on whether or not to complete each application. Non-pecuniary preferences

3. Compute the reservation wages of each candidate, given the non-pecuniary benefits estimated in step 2. Reservation wages

4. Simulate the winning candidate (conditional on reservation wages found in step 3) and compute moments. Choosing the winner

5. Update the value of $\widehat{\epsilon}_n$, and return to step 2.

Estimation
Stage 2: Productivity terms and preferences of applicants

We estimate the productivity parameters using GMM, where the moments compare the characteristics of the person offered the job in the data to the person offered the job in the simulation

- Education
- Gender
- Race
- Gender
- Experience at the firm
- Wage

The moments are interacted with the following instruments

- Share of interviewed candidates with each education level
- Race and gender distribution of interviewed candidates
- Internal experience of interviewed candidates
- Salary level of the job
- Number of people interviewed for the position

Estimation
Stage 3: Committee preferences

- The committee chooses the interview set to maximize its preferences plus the surplus from the winning candidate.

$$\int \sum_{(c_1, c_2) \in \mathbb{C}} \mathbf{1}\left\{(c_1, c_2) = (a, b)\right\} \left[L_{c_1} + M\left(\pi_{c_1}, \overline{w}_{c_2}\right)\right] \prod_{c \in \mathbb{C}} dF_c\left(\pi_c, \overline{w}_c\right) - \lambda \left|C\right|$$

- The committee considers all interview sets and chooses the optimal one
    - There is a very large set of choices. We make the computation feasible by eliminating *infeasible* sets
    - Recall that there is a term η_c in L_c that is only observed by the committee. These are simulated in estimation.
    - Suppose candidate A and B both have the same type x_{an}, but A has a higher simulated η than B. Then candidate B will never be interviewed when candidate A is not interviewed.

- We simulate the optimal interview set for a given set of parameters.
- We then compute moments which compare the demographic characteristics of the simulated and actual interview set.
- We estimate using GMM by interacting the moments with instruments that include the characteristics of the applicant pool, the number of applicants, and the salary of the job.

Results
Non-pecuniary benefits of employment

We divide jobs according to the division of the position. Non-pecuniary benefits of a job in a division depend on demographic characteristics.

		Division			
		1	2	3	4
Constant		6,306.5	22,685.2	-2,033.5	-4,186.4
		(2714.37)	(4146.09)	(3504.63)	(2413.56)
Some college	382.7	4,242.6	-5,911.7	-3,351.2	657.9
	(612.91)	(2816.97)	(4339.26)	(3687.83)	(2557.42)
College	-1,162.4	2,359.3	-6,871.4	920.4	3,156.9
	(584.76)	(2708.02)	(4148.67)	(3703.48)	(2517.27)
Post college	-690.9	8,909.6	-19,285.6	2,280.1	-1,972.4
	(956.15)	(3192.01)	(4863.40)	(4222.44)	(2826.32)
Female	-2786.0	-3,909.9	-2,363.6	3,957.0	4,009.6
	(546.31)	(1698.89)	(2687.89)	(2395.99)	(1713.54)
Black	-2,408.1	-20,879.2	-8,954.2	6,003.4	-5,184.2
	(1742.99)	(4609.55)	(5420.93)	(4710.01)	(4895.67)

Results
Productivity parameters

Parameter	Estimate	Parameter	Estimate
High school	-8,037.1	Value of a vacancy	8,619.3
	(859.7)		(448.6)
Some college	-6,529.7	Mean of relocation cost	-4,709.9
	(779.3)		(304.0)
College	4,804.4	Standard deviation of	9,947.5
	(946.5)	relocation cost	(314.1)
Female	559.3	Standard deviation of	9,953.9
	(32.0)	unobserved productivity term	(737.9)
Black	-6,517.5		
	(674.2)		
Internal	9,998.8		
	(9998.8)		

Results
Committee preferences

	Estimate
High school	-1,780.2
	(145.08)
Some college	-1,685.9
	(71.86)
College	-1,355.4
	(383.27)
Female	-742.2
	(34.64)
Black	-6641.5
	(401.56)
Internal	3665.5
	(506.12)
Cost of interview	416.4
	(24.49)
Standard deviation of unobserved	6,938.4
committee preferences	(203.44)

Results
Model fit - characteristics of interviewed and hired candidates

| | Share of candidates | | | |
| | Interviewed | | Hired | |
	Model	Data	Model	Data
Women	0.50	0.54	0.57	0.57
Black	0.022	0.30	0.033	0.029
Internal to firm	0.076	0.084	0.072	0.11
High school	0.13	0.15	0.14	0.15
Some college	0.31	0.33	0.33	0.32
College	0.39	0.38	0.39	0.39
Post college	0.17	0.14	0.13	0.14
Total number of interviews	4.28	4.93		
Wage of hired candidate			38,381.3	38,306.0

Counterfactuals
Role of divergent preferences

- CF1: Observed committee preferences over characteristics are set to 0.
- CF2: We additionally set the unobserved committee preferences to 0.

	Interviewed candidates			Hired candidates		
	Baseline	CF1	CF2	Baseline	CF1	CF2
Women	0.50	0.51	0.58	0.51	0.51	0.58
Black	0.022	0.044	0.054	0.030	0.051	0.046
Internal to firm	0.076	0.065	0.037	0.099	0.080	0.048
High school	0.13	0.13	0.14	0.14	0.14	0.15
Some college	0.31	0.31	0.35	0.32	0.32	0.37
College	0.39	0.39	0.38	0.38	0.38	0.37
Post college	0.17	0.16	0.13	0.17	0.16	0.12
Num. of interviews	4.28	4.34	7.44			
Manager valuation					3.12%	102.32%
Obs. comm. pref.					-19.0%	-40.0%
Unobs. comm. pref.					-0.62%	-76.89%

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Some college	0.31	0.31	0.35	0.32	0.32	0.37
College	0.39	0.39	0.38	0.38	0.38	0.37
Post college	0.17	0.16	0.13	0.17	0.16	0.12
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High school	0.13	0.13	0.14	0.14	0.14	0.15
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Counterfactuals
Role of gender and race considerations

- When some firms make hiring decisions, they do not allow the interview committee to see the race and gender of each applicant.
- We simulate interview and hiring decisions in this environmen.

	Interviewed candidates		Hired candidates	
	Baseline	Counterfactual	Baseline	Counterfactual
Women	0.50	0.53	0.51	0.54
Black	0.022	0.047	0.030	0.059
Internal to firm	0.076	0.072	0.099	0.10
High school	0.13	0.13	0.14	0.14
Some college	0.31	0.31	0.32	0.32
College	0.39	0.39	0.38	0.38
Post college	0.17	0.17	0.17	0.16
Num. of interviews	4.28	4.47		
Manager valuation				8.41%
Obs. comm. pref.				-15.79%
Unobs. comm. pref.				-4.25%

- Expected duration affects the returns to hiring a candidate.
- In the data, women stay at jobs for shorter durations, lowering the value of hiring a woman to the firm.
- Minority candidates also have shorter durations.
- We equalize the expected durations across race and gender to see the role of durations in interview probabilities and hiring.

Counterfactuals
Role of expected durations

- CF4: Use the durations of white male candidates.
- CF5: Use the durations of non-white female candidates.

	Interviewed candidates			Hired candidates		
	Baseline	CF4	CF5	Baseline	CF4	CF5
Women	0.50	0.52	0.51	0.51	0.51	0.51
Black	0.022	0.034	0.037	0.030	0.047	0.048
Internal to firm	0.076	0.074	0.084	0.099	0.10	0.11
High school	0.13	0.13	0.14	0.14	0.14	0.14
Some college	0.31	0.31	0.31	0.32	0.32	0.32
College	0.39	0.39	0.38	0.38	0.38	0.38
Post college	0.17	0.17	0.17	0.17	0.16	0.17
Num. of interviews	4.28	4.43	3.54			
Manager valuation					-14.7%	59.3%
Obs. comm. pref.					-10.2%	-6.3%
Unobs. comm. pref.					-5.5%	13.1%

Counterfactuals
Role of committee decisions

- In our model, the interview committee chooses an optimal interview set, which then generates some value M for the manager.
- What is the value of this screening process?
- In the next counterfactual, we simulate an environment where every candidate is equally likely to be interviewed.
- To get the same valuation M as with the model, we will have to interview more candidates.

- In the baseline, we simulate the optimal interview set , and compute the manager's expected valuation M for that interview set
- In the counterfactual, we randomly generate interview sets, starting with 2 interviewed candidates and then increasing the size of the consideration set.

Counterfactuals
Role of committee decisions

Int.				Num. interviewed in baseline		
(CF)	Outcome	Total		Fewer	Same	More
	Manager value	-1295%			-21%	-1,825%
2	Obs. comm. pref.	-101,577%			-320,519%	-10,373%
	Unobs. comm. pref.	-712%			-65%	-74%
	Manager value	-692%		37%	-10%	-1,172%
3	Obs. comm. pref	-111,351%		-415,665%	-48,097%	-124%
	Unobs. comm. pref.	-77%		-85%	-56%	-79%
	Manager value	-158%		69%	-114%	-536%
5	Obs. comm. pref	-136,468%		-272,385%	-221%	-142%
	Unobs. comm. pref.	-85%		-87%	-78%	-87%
	Manager value	13%		101%	-42%	-206%
6	Obs. comm. pref	-140,769%		-214,430%	-9,698%	-171%
	Unobs. comm. pref.	-88%		-88%	-82%	-90%

Counterfactuals

Role of committee decisions

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	Unobs. comm. pref.	-88%	-88%	-82%	-90%

Conclusion

- We develop an equilibrium model where firms choose who to hire using a multi-stage process.
  1. What is the optimal interview set?
  2. Who is hired?

- Wages are determined in equilibrium as a function of the competition for a position.

- We estimate the model using application and wage data from a large firm.

- Counterfactuals:
  - Do we see evidence of competing interests within the firm?
  - What happens if the interview selection process is race and gender blind?
  - How does the firm selection process impact the surplus from who is hired? What happens under alternate mechanisms?

Descriptive statistics
Worker decisions vary with demographic characteristics

1. Job search:
   - Women and African Americans apply for more jobs.
     Number of applications
   - Women and African Americans apply to lower salary jobs.
2. Application decisions:
   - Women and African Americans are less likely to complete applications.
3. Wages:
   - Women and African Americans earn less, and this holds (for women) even when we condition on the salary range when the vacancy was advertised.
4. Durations:
   - Women and African Americans have shorter durations on the job.

Data

Data
Number of applications by race and gender

	All	Qualified and interested
	(1)	(2)
African American	0.701***	0.341***
	(0.0715)	(0.0465)
Female	0.108***	0.0922***
	(0.0306)	(0.0199)
Duration working for firm	0.140***	0.131***
	(0.0254)	(0.0165)
Observations	87394	87394

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The dependent variable is the number of applications submitted. Controls for year, education, and age included but not reported. We additionally control for the square of the duration working for the firm. Data

Data
Regressing average salary of job posting on race and gender (and other variables)

	All		Qualified and interested	
	(1)	(2)	(3)	(4)
African American	-1120.5***	-266.7	-1329.5***	-971.1**
	(65.06)	(393.6)	(76.37)	(461.9)
Female	-523.2***	-1888.2***	-600.6***	-2094.9***
	(34.80)	(174.0)	(39.87)	(197.3)
Previous year salary		0.180***		0.191***
		(0.00480)		(0.00541)
Observations	227198	10549	158326	8071

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. The job posting reports the minimum and maximum salaries. The dependent variable is the average of those 2 values. We additionally control for the number of applications, experience working for the firm, location of the position, age, and education. We also include division and occupation fixed effects. Data

Withdrawal of applications

Dependent variable: withdraw application	
African American	0.0106***
	(0.00268)
Female	0.00729***
	(0.00148)
Number of applications submitted per year	0.000750***
	(0.0000593)
Number applications for job	-0.0000815***
	(0.00000606)
Average salary of posted job	-0.00000327***
	(0.000000106)

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. We report marginal effects from a probit regression. We also control for eduation and age, the location of the job and its fulltime status, experience at the firm and division, and include year, division, and occupation fixed effects.

Data

	All	Job switchers
African American	-0.101 ***	-0.0632
Female	-0.0938 ***	-0.0920 ***
Duration in current division	0.0957 ***	0.0540 ***
Experience squared	-0.00337 ***	-0.00184 ***
Switches divisions	0.142 ***	0.0678
Number applications for job		-0.000300 ***
Salary of job posting		0.0000203 ***
Constant	9.776 ***	9.125 ***
Observations	50519	1210

We additionally control for age and education, and include year and division fixed effects. We include occupation fixed effects in column (2). Data

Data
Duration of job(s) within a division

	OLS	Tobit
African American	-0.919***	-1.176***
	(0.215)	(0.288)
Female	-0.304***	-0.761***
	(0.101)	(0.135)
Year job started		0.809***
		(0.00995)
Observations	11342	11342

We additionally control for education, unemployment and labor market participation in a given year, and include division and occupation fixed effects. Data

Descriptive statistics
Firm decisions vary with demographic characteristics

1. An initial screen eliminates unqualified candidates.
   - African American candidates are more likely to eliminated at this stage.
2. Candidates are selected for an interview.
   - African American candidates are less likely to be interviewed.
3. One candidate is hired for an open position.
   - African American candidates are more likely to be hired.

   Data

Not qualified for a position

Not qualified for a position	
African American	0.0193***
	(0.00157)
Female	-0.0000539
	(0.000784)
Number of applications submitted per year	0.000987***
	(0.0000456)
Number applications for job	-0.000357***
	(0.0000132)
Average salary of posted job	0.00000278***
	(0.000000108)

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. We report marginal effects from a probit regression. We also control for education and age, experience at the firm and division, location of the job and its full time status, and include year, division, and occupation fixed effects. Data

Dependent variable: interviewed	
African American	-0.0315***
	(0.00505)
Female	-0.00253
	(0.00251)
Number of applications per year	-0.00523***
	(0.000123)
Number of candidates	-0.000681***
	(0.0000153)
Average salary of posted job	0.00000166***
	(0.000000157)

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. We report marginal effects from a probit regression. We also control for eduation and age, experience at the firm and division, the location of the job and its fulltime status, and include year, division, and occupation fixed effects. Number of candidates refers to the number of qualified and interested candidates for a given position. Data

Hired

Dependent variable: hired	
African American	0.0228**
	(0.00965)
Female	0.00834*
	(0.00443)
Number of applications per year	-0.00929***
	(0.000353)
Number of people interviewed	-0.00219***
	(0.0000825)
Average salary of posted job	5.40e-08
	(0.000000242)

Standard errors in parentheses. $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. We report marginal effects from a probit regression. We also control for eduation and age, experience at the firm and division, the location and fulltime status of the position, and include year, division, and occupation fixed effects.

Data

Model
Workers objective

- $i \in \{1, 2, \ldots\}$ is a job spell, and $j \in \left\{1, 2, \ldots, j^{(i)}\right\}$ is an employment opportunity within a spell
- Worker chooses $d_j^{(i)} \in \{0, 1\}$, which is whether or not to pursue j^{th} employment vacancy in spell i
- Worker chooses $\left\{ d_j^{(i)} \right\}$ for each (i, j) to maximize:

$$
E \left[\sum_{i=1}^{\infty} \left\{ \begin{array}{l} \delta^{-1} \left[\exp\left(-\delta \tau^{(i)} \right) - \exp\left(\tau^{(i+1)} \right) \right] \left(w^{(i)} + u^{(i)} \right) \\ + \exp\left(-\delta \tau^{(i)} \right) \epsilon^{(i)} + \sum_{j=1}^{j_i} d_j^{(i)} \exp\left(-\delta \rho_j^{(i)} \right) \xi_j^{(i)} \end{array} \right\} \right]
$$

- δ is a (continuous) discount factor
- $\tau^{(i)}$ is the time the ith spell begins
- $w^{(i)} + u^{(i)}$ is the flow of compensation (wage and amenities) in i

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  - $\epsilon^{(i)}$ is an initial adjustment or job relocation cost

- $i \in \{1, 2, \dots\}$ is a job spell, and $j \in \left\{1, 2, \dots, j^{(i)}\right\}$ is an employment opportunity within a spell
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$$

- $\xi_j^{(i)}$ cost of following through with employment opportunity
- $\rho_j^{(i)}$ random time of jth employment opportunity

Worker application decision

- Consider a static example where $M(x, \pi, w) = \pi - w$ to understand how the winner is picked and equilibrium wages are determined.

$$\pi_A = 12 \qquad \pi_B = 15 \qquad \pi_C = 10$$
$$r_A = 10 \qquad r_B = 11 \qquad r_C = 10$$

- The manager lowers the worker's value of employment until 1 candidate remains.
- Let's start with the wages such that $M = 1$. The wages are

$$w_A = 11 \qquad w_B = 14 \qquad w_C = 9$$

Worker C is below his reservation wage and drops out.

- Now let's increase to $M = 2$. The wages are

$$w_A = 10 \qquad w_B = 12$$

Worker A is indifferent between the job and his old job, so he drops out. This means B is the winner and gets paid $w_B = 12$. Hiring decision

Model
Reservation wages

- To solve for the value of hiring a worker $M(\cdot)$, we need to know each person's reservation wage.
- This can be solved from the worker's decision problem.
- Denote ϵ as the relocation cost of moving to a new job.
- We solve for the reservation wage by setting $\overline{V}_1 - V_0 = \epsilon$:

$$
\begin{aligned}
\overline{w} &= w + (x - \widehat{x})\,\gamma \\
&\quad + (1 - E\left[\exp\left(-\delta\rho\right)\right])^{-1} \delta \left[E\left[-\exp\left(-\delta\rho\right)\right]\left(V - \overline{V}\right) + \epsilon \right]
\end{aligned}
$$

- The difference $\left(V - \overline{V}\right)$ can be expressed as a function of the *conditional choice probabilities*, which in turn depend on $\overline{w}$.
- $\overline{V}$ is decreasing in $\overline{w}$, implying the solution to the equation is unique.

Hiring decision

Empirical Methods
Stage 2: Non pecuniary benefits

- An application is completed if $\xi \leq V_1 - V_0$
- We compute the log odds ratio of completing an application

$$
\begin{aligned}
y_{an} &= (\widehat{x}_{an} - x_{an})\, \gamma + \nu_{an} \\
y_{an} &= \ln\left(\frac{p_{an}}{1 - p_{an}}\right) \\
&\quad - \frac{\phi_{an}}{\delta\left[1 - E\left[\exp\left(-\delta\rho_{an}\right)\right](1 - \phi_{an})\right]}
\left[\begin{array}{l} E\left[(1 - \rho_{an})\left(\widehat{w}_{an} - w_{an}\right)\right] \\ -E\left[\exp\left(-\delta\rho_{an}\right)\right]\left\{\widehat{\epsilon}_{an}^{(s)} + \end{array}\right.
\end{aligned}
$$

- If $E\left[\widehat{\epsilon}_{an}\right]$ was known we could estimate γ with OLS.
- We solve for γ conditional on our guess for $\widehat{\epsilon}_{an}$.

Estimation

- Given the estimated values of γ, we compute reservation wages for **internal candidates**
- Recall the derivation of the reservation wages in the model

$$\begin{aligned}
\overline{w}_{an} &= w_{an} + (x_{an} - \widehat{x}_{an})\,\gamma \\
&\quad + (1 - \rho_{an})^{-1}\,\delta\left[\rho_{an}\left(V_{an} - \overline{V}_{an}\right) + \epsilon_{an}^{(s)}\right]
\end{aligned}$$

- For **external candidates**, we predict reservation wages using the Survey for Consumer Expectations Labor Market Survey, which reports responses on individual reservation wages. Estimation

Estimation
Stage 2: Predict who is hired

For each interviewed candidate c for job n, we can compute

$$M\left(\pi_{cn}, \overline{w}_{cn}\right) = \left(1 - E\left[\exp\left(-\delta\widehat{\tau}_{cn}\right)\right]\right)\left(x_{cn}\alpha + \zeta_{cn}^{(s)} - \overline{w}_{cn}\right) + E\left[\exp\left(-\delta\widehat{\tau}_{cn}\right)\right]$$

- $\widehat{\tau}_{cn}$ is how long the candidate stays at a job
- x_{cn} is individual characteristics, α are the productivity parameters
- $\zeta_{cn}^{(s)}$ is an individual productivity shock (simulated)
- $\overline{w}_{cn}$ is the reservation wage
- M_0 is the value of a vacancy

The candidate with the highest $M\left(\cdot\right)$ gets the job offer. The second best candidate is used to pin down the equilibrium wage. We go back to step 2 using the $\widehat{\epsilon}$ of the winner. Estimation