Training, Offshoring, and the Job Ladder
NBER ITI meetings

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Post 1980 trends in U.S. Labor markets

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- Manufacturing work force has shifted toward services (Lee and Wolpin, 2006, 2010; Eberstein et al., 2014)
Fraction of the population attending college has grown (Acemoglu and Autor, 2011)
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- On-the-job training times have increased (Cairo, 2013)

- Life-cycle career trajectories have evolved very differently for different types of workers
  - job to job transitions
  - unemployment spells
  - education and on-the-job training
The modeling exercise

- Develop an open economy search model that
  - generates predictions on all these variables.
  - links them to globalization and skill-biased technical change
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- Show its possible to explain aggregate trends and changing life-cycle patterns by shocking returns to different tasks.
- Link task returns to globalization and technology shocks (in progress).
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- Link task returns to globalization and technology shocks (in progress).

- Related literature.  ▶ references
The basic mechanics

- Heterogeneous high school graduates decide whether to attend college.
- After completing schooling, new workers enter into the labor market and eventually match with differentiated employers.
- Once employed, workers bargain over their wages and may also improve their ability through investments in on-the-job training.
- Over their life cycles, workers' wage growth is driven by improvements in ability, shocks to employer profitability, arrival of job offers from poaching employers ("job ladder"), and unemployment spells.
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While improving productive efficiency, globalization reduces relative supply of jobs in the trade-exposed occupations.

- Slows down turnover by limiting outside options of employees.
- Low arrival rate of attractive job offers means
  - slows movement up job ladder
  - more likely to separate into unemployment and lose bargaining power.
Effects of globalization

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- Similarly, globalization affects training incentives:
  - Those with college degrees see greater returns to on-the-job training.
  - Those without degrees are forced into jobs with little scope for training or on-the-job learning.
Effects of technological change

- Originate with changes in production function parameters.

- Like globalization, technological change affects task prices in equilibrium
  - Affect career paths though same mechanisms as globalization.
  - But changes in relative task prices are distinct.
  - Identification of technology effect comes from changing shares of tasks in production
Some stylized facts: data

- **Data sets:**
  - **Survey of Income and Program Participation (SIPP):** nationally representative U.S. household-based survey; continuous series of national panels, each lasting approximately four years
  - **Occupational Information Network (O*NET):** skill mix (brain, brawn) of 4-digit occupations
  - **World I-O Table (WIOT):** imports, exports and output by sector
  - **Occupational Employment Statistics (OES):** Annual employment and wage estimates for about 800 occupations, broken down by industry.
  - **Panel Study of Income Dynamics (PSID):** Nationally representative household survey. Series of annual waves between 1968 and 1997; biennial thereafter. Annual earnings and tenure by job, occupation, industry.
Some stylized facts: data

- **Variables:**
  - **Job flows** employment-weighted average monthly flows by 4-digit 2002 Standard Occupational Code (SOC)
  - **Employment shares** by sector (SIPP, OES)
  - **Trade exposure indices:** import penetration rates, by sector (WIOT), occupation (SIPP)
  - **Brain, brawn content of occupations:** based on principal components of O*NET job characteristics
  - **Training indicator:** Have you received job training? (SIPP)
  - **Import exposure of occupations** (OES and WIOT) employment weighted average of sectoral import penetration rates.
  - **Earnings-tenure profiles** (PSID) by job, sector, and occupation.
Employment shares have fallen more in sectors with growing trade exposure.

Sectors losing employment shares have tended to be in the middle of the wage distribution. (See also: Acemoglu and Autor, 2011.)
Figure: Changes in Monthly Job-to-Job Transitions

- Turnover has fallen more at the low end of the skill distribution. (See also: Davis and Haltiwanger, 2014; Cairo et al., 2015.)
Change in E-to-U transition rates, 2010 vs. 1990

**Figure:** Change in Monthly E-to-U Transitions

- Separations into unemployment rose at the low end of the skill distribution.
Figure: Change in the Fraction of Trained Workers

- Training has increased in most occupations, but decreased or remained stable in low-skill occupations.
Figure: Labor Earnings by Age and Tradability of Occupations

- Profile for tradable occupations flattens relative to others.
- Transition or new steady state?
The earnings gap between trained and untrained workers has grown.

- Search and matching frictions, worker poaching in the labor market (Mortensen and Pissarides 1999, Mortensen 2010)

- Ricardian production and trade with sectoral linkages (Caliendo and Parro 2014)

- Three types of agents:
  - worker/consumers
  - goods producers
  - task producers

  - why task producers?
Model structure: goods producers

- Goods producers combine bundles of labor services (tasks) and bundles of product varieties to generate output.
  - Factor intensities (both task and intermediate bundles) vary across sectors
  - Output goes to consumers and to other producers (as intermediate inputs)

- Product markets are as in Caliendo and Parro, 2015).
  - Intermediate goods are sourced globally from their cheapest suppliers.
  - Offshoring occurs when a variety is sourced abroad.
  - Direct offshoring of labor services nested as a sector that uses no intermediates.
The environment: worker-consumers

- Born with an initial ability level $a_0$ drawn from $F_{a_0}(\cdot)$
- Either invest in a college degree (become an $H$-type) or enter the labor market immediately as low-skilled ($L$-type) worker.
- Those who go to college incur a utility cost of $\kappa/a_0$
- Stochastically improve their ability level, $a \in \{a^1, \ldots, a^l\}$, through on-the-job experience and (perhaps) training.
- **Hazard of a one-step improvement** for a worker in state $(E, a)$ at a firm producing type-$j$ services ("tasks") with productivity $z$:

  $$\gamma_E(a,j,z) = \gamma^1_{j,E} + \gamma^2_{j,E} 1_E^t(a,j,z)$$

  where $E \in \{H, L\}$ and $1_E^t(a,j,z) = 1$ if the worker and her employer have agreed to training (Flinn et al., 2017).
The environment: task-producing firms

- Specialize in producing a particular service ("task"), indexed by $j \in \{1, \ldots, J\}$
- One worker or vacancy per firm. Flow vacancy posting cost: $c_v$
- Employ workers they match with in a frictional labor market.
- May or may not invest in the training of their employees.
- Experience ongoing, idiosyncratic productivity shocks, $z$.
- Supply output $y_E(a, j, z)$ in competitive national market at price $r_j$. Task production technology:

$$y_E(a, j, z) = zs_j a^{\zeta_{j,E}} - c^t 1^t_E(a, j, z) - c^o$$

where $s_j$ is a productivity index for task $j$. and $\zeta_{j,E}$ measures return to ability for type $(j, E)$ workers.
Worker productivity by human capital and occupation

- Darker shades reflect higher productivity.

- Workers increase wages by improving ability (downward movement) or moving across employers, occupations (rightward movement).

- Workers care about market thickness, not just wages.
Random matching

- Total measure of vacant jobs in occupation $j$: $V_j$

- Measure of jobs seekers’ visibility to type-$j$ employers:

$$Z_j = \lambda_0^L U_L + \lambda_0^H U_H + \sum_{\tilde{j}} \lambda_{j,\tilde{j}} N_{\tilde{j}}$$

where

- $U_H$ and $U_L$ are masses of low- and high-education unemployed workers, respectively
- $N_{\tilde{j}}$ is the mass of employed workers in occupation $\tilde{j}$
- $\lambda_{j,\tilde{j}}$ controls the visibility of a worker currently producing task $\tilde{j}$ to a type-$j$ task-producing firm
Random matching

- **Matching function:**

\[
m(V_j, Z_j) = \frac{V_j Z_j}{(V_j^\chi + Z_j^\chi)^{\frac{1}{\chi}}}
\]

- **Visibility function:**

\[
\lambda_{j,\tilde{j}} = \frac{\lambda}{[1 + d(j, \tilde{j})]^\xi}
\]

where

\[
d(j, \tilde{j}) = \sqrt{\left(\nu^j - \nu^{\tilde{j}}\right)' \Sigma^{-1} \left(\nu^j - \nu^{\tilde{j}}\right)},
\]

\(\nu^j\) is vector of brain and brawn indices.
Wage setting

- Wage setting with on-the-job search based on Mortensen (2011). (Alternatives: Bagger et al., 2014; Lise et al., 2016)
  - Negotiation with unemployed workers
  - Renegotiation after outside offers
  - Renegotiation after productivity shocks
  - Renegotiation after human capital shocks
Value of employment reflects:

- flow earnings
- capital loss from death shock
- capital gain/loss from productivity shock, recognizing quit option
- capital gain/loss from ability shock, recognizing quit option.
- size and likelihood of outside offers
Value of a filled vacancy

- Value of an active job reflects:
  - exogenous separation hazards
  - expected capital gains/losses from productivity shocks
  - expected capital gains/losses from worker ability shocks
  - expected capital losses due to poachers

- Let $\Pi^v(j, z)$ be value of unfilled vacancy. Task producer free entry condition.

$$\sum_{z \in Z} \Pi^v(j, z) \Gamma(z) \geq 0 \quad \forall j \in \Omega$$
College decision depends on initial ability, $a_0$:

$$E(a_0) = \begin{cases} 
H & \text{if } \frac{k}{a_0} \leq J_H^u(a_0) - J_L^u(a_0) \\
L & \text{otherwise}
\end{cases}$$

Training decisions maximize the joint surplus of each match:

$$1^t_E(a, j, z) = \begin{cases} 
1 & \text{if } S_E(a, j, z; 1^t(a, j, z, E) = 1) \\
\geq S_E(a, j, z; 1^t(a, j, z, E) = 0) & \text{otherwise}
\end{cases}$$
Baseline period: 2005-2008

Countries: 30 + ROW

Industries: 30 ISIC Rev.3.1 (15 tradable)

Occupations: 5 SOC 1-digit

Model numeraire: monthly labor income per employee (USD 3,700)

The economy is assumed to be in steady state

Production function parameters calibrated directly from expenditure shares in production data
Task production

- Initial distribution of human capital assumed to be Beta with shape parameters $\alpha_{a_0}$ and $\beta_{a_0}$

- Task-producing technology: $y_E(j, z, i) = zs_j a_i^\zeta j,E - c^o$

- Permanent productivity assumed to be increasing in skill content:
  \[ s_j = (1 + \Delta s)^{\text{brain}_j}, \quad \text{brain}_j \in (0, 1) \]

- Productivity shocks assumed following the Poisson jump process with hazard $\varphi$ and realization equal to:
  \[ z' = \begin{cases} 
  z + \Delta z & \text{with probability } \frac{1}{2} \left(1 - \frac{z}{n\Delta z}\right) \\
  z - \Delta z & \text{with probability } \frac{1}{2} \left(1 + \frac{z}{n\Delta z}\right) \\
  0 & \text{other}
  \end{cases} \]
  along the support $Z \equiv \{-n\Delta z, -(n - 1)\Delta z, \ldots, 0, \ldots, n\Delta z\}$ and $n = 100$
### Parameters taken from the literature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>Discount factor</td>
<td>0.0033</td>
<td>4% yearly</td>
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<tr>
<td>$\delta_w$</td>
<td>Retirement rate</td>
<td>0.0023</td>
<td>ages 25-60</td>
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<tr>
<td>$\delta_f$</td>
<td>Firm exit rate</td>
<td>0.0045</td>
<td>BLS 2005</td>
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<tr>
<td>$\beta$</td>
<td>Bargaining power</td>
<td>0.50</td>
<td>Pissarides (2009)</td>
</tr>
<tr>
<td>$\chi$</td>
<td>Matching function</td>
<td>0.45</td>
<td>Den Haan et al (2006)</td>
</tr>
<tr>
<td>$(b_L, b_H)$</td>
<td>Home production</td>
<td>(0.31, 0.52)</td>
<td>ACS 2005</td>
</tr>
<tr>
<td>$c_v$</td>
<td>Cost of vacancy</td>
<td>0.29</td>
<td>Abowd and Kramarz (2003)</td>
</tr>
<tr>
<td>$c_t$</td>
<td>Cost of training</td>
<td>0.16</td>
<td>Abowd and Kramarz (2003)</td>
</tr>
<tr>
<td>$(\alpha_{a_0}, \beta_{a_0})$</td>
<td>Distribution of $a_0$</td>
<td>(2.11, 2.45)</td>
<td>AFQT test distribution</td>
</tr>
<tr>
<td>$(\varphi, \Delta z)$</td>
<td>Productivity shock</td>
<td>(1.57, 0.24)</td>
<td>Lee and Mukoyama (2015)</td>
</tr>
</tbody>
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Parameters from literature, continued

<table>
<thead>
<tr>
<th>Parameters</th>
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<th>Source</th>
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<tr>
<td>$\eta$</td>
<td>Elasticity of substitution between varieties $\omega$</td>
<td>Broda and Weinstein (2006)</td>
</tr>
<tr>
<td>$\tau_{n\tilde{n}}^k$</td>
<td>Bilateral tariffs (countries $n$-$\tilde{n}$, sector $k$)</td>
<td>Caliendo and Parro (2015)</td>
</tr>
<tr>
<td>$\theta_k$</td>
<td>Dispersion Frechet (sector $k$)</td>
<td>Caliendo and Parro (2015)</td>
</tr>
</tbody>
</table>

**Estimated**

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>$\nu^k_n$</td>
<td>Consumption elasticity of product $k$ (country $n$)</td>
<td>WIOD-IOT (2013)</td>
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<tr>
<td>$\vartheta^n_{k\tilde{k}}$</td>
<td>Output elasticity of product $\tilde{k}$ (country $n$, sector $k$)</td>
<td>WIOD-IOT (2013)</td>
</tr>
<tr>
<td>$\alpha^n_k$</td>
<td>Output elasticity of labor tasks (country $n$, sector $k$)</td>
<td>KLEMS (2017)</td>
</tr>
<tr>
<td>$\mu^n_{kj}$</td>
<td>Labor tasks elasticity of task $j$ (country $n$, industry $k$)</td>
<td>OES (2017)</td>
</tr>
<tr>
<td>Moments</td>
<td>Data (2005)</td>
<td>Model</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>Labor income</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>College premium</td>
<td>0.557</td>
<td>0.491</td>
</tr>
<tr>
<td>St.Dev., non-college</td>
<td>0.605</td>
<td>0.375</td>
</tr>
<tr>
<td>St.Dev., college</td>
<td>0.735</td>
<td>0.641</td>
</tr>
<tr>
<td>45-25 y.o. premium, non-college</td>
<td>0.191</td>
<td>0.144</td>
</tr>
<tr>
<td>45-25 y.o. premium, college</td>
<td>0.382</td>
<td>0.376</td>
</tr>
<tr>
<td>Training premium</td>
<td>0.356</td>
<td>0.103</td>
</tr>
<tr>
<td>Brain-skill premium</td>
<td>0.337</td>
<td>0.199</td>
</tr>
<tr>
<td><strong>Labor market flows</strong></td>
<td></td>
<td></td>
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<tr>
<td>NE-E rate</td>
<td>0.022</td>
<td>0.016</td>
</tr>
<tr>
<td>E-NE rate</td>
<td>0.023</td>
<td>0.025</td>
</tr>
<tr>
<td>J-J rate</td>
<td>0.019</td>
<td>0.022</td>
</tr>
<tr>
<td><strong>Shares</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>College share</td>
<td>0.281</td>
<td>0.310</td>
</tr>
<tr>
<td>Training share</td>
<td>0.392</td>
<td>0.304</td>
</tr>
</tbody>
</table>

\[
\theta = \{ \kappa, \Delta_s, \zeta^E, c_0, \gamma_E^1, \gamma_E^2, \lambda_0, \lambda_1, \zeta \}. \\
\text{education, production (4), training (4), visibility (3)}
\]
Parameters based on moment vector

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<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>$\kappa$</td>
<td>Cost of college education</td>
<td>181.02</td>
</tr>
<tr>
<td>$c^o$</td>
<td>Cost of operating</td>
<td>1.18</td>
</tr>
<tr>
<td>$\Delta_s$</td>
<td>Permanent productivity</td>
<td>0.64</td>
</tr>
<tr>
<td>$\lambda_0$</td>
<td>Visibility, unemployed</td>
<td>0.032</td>
</tr>
<tr>
<td>$(\lambda_1, \zeta)$</td>
<td>Visibility, employed</td>
<td>(0.038, 0.02)</td>
</tr>
<tr>
<td>$(\zeta^L_0, \zeta^H_0)$</td>
<td>Return from human capital</td>
<td>(0.09, 0.24)</td>
</tr>
<tr>
<td>$(\gamma^L_0, \gamma^H_0)$</td>
<td>Experience, hazard rate</td>
<td>(0.03, 0.05)</td>
</tr>
<tr>
<td>$(\gamma^L_1, \gamma^H_1)$</td>
<td>Training, hazard rate</td>
<td>(0.06, 0.15)</td>
</tr>
</tbody>
</table>
Suppose something changes task prices—either trade shock or a technology shock—in a way consistent with observed data. What happens to labor market dynamics?

Proxy changes in prices of tasks, $\Delta r_j$, using changes in wages by occupations (between 1990 and 2005)

<table>
<thead>
<tr>
<th>tasks $j$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-digit SOC</td>
<td>51-53</td>
<td>45-49</td>
<td>31-39</td>
<td>41-43</td>
<td>11-29</td>
</tr>
<tr>
<td>Brain-content</td>
<td>0</td>
<td>0.056</td>
<td>0.134</td>
<td>0.236</td>
<td>1</td>
</tr>
</tbody>
</table>

$\Delta r_j$, %  
0.767 0.845 1.106 0.872 1.592

$\Delta r_j$, %  
+3.55 -4.14 -1.62 -2.43 +10.12
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<td>0.236</td>
<td>1</td>
</tr>
<tr>
<td>Employment share, $\Delta$  %</td>
<td>+0.9</td>
<td>-1.5</td>
<td>-0.8</td>
<td>-0.7</td>
<td>+2.1</td>
</tr>
<tr>
<td>J-J rate, $\Delta$ %</td>
<td>-1.06</td>
<td>-0.57</td>
<td>-0.43</td>
<td>-0.48</td>
<td>0.02</td>
</tr>
<tr>
<td>E-NE rate, $\Delta$ %</td>
<td>+0.01</td>
<td>+0.60</td>
<td>+0.40</td>
<td>+0.07</td>
<td>-0.05</td>
</tr>
<tr>
<td>Training share, $\Delta$ %</td>
<td>-1.03</td>
<td>-27.23</td>
<td>-15.39</td>
<td>-11.20</td>
<td>+12.54</td>
</tr>
<tr>
<td>Labor income, avg. %</td>
<td>+2.61</td>
<td>-4.12</td>
<td>-3.12</td>
<td>-1.04</td>
<td>+6.01</td>
</tr>
<tr>
<td>Labor income growth, 45-25 y.o. %</td>
<td>+0.02</td>
<td>-5.32</td>
<td>-3.45</td>
<td>-0.95</td>
<td>+7.32</td>
</tr>
</tbody>
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Next steps

- Use full range of occupations and sectors, and calibrate more seriously

- Using only changes in openness, ask how well the model predicts:
  - job turnover slowdown at each skill level
  - shifts in training and education patterns
  - changes in wages

- Explore added contribution of skill-biased technological change.

- Consider counterfactual policy experiments with commercial policy, education subsidies, training subsidies
• **On-the-job search and bargaining with ex ante heterogeneous workers and firms:** Postel-Vinay and Robin (2002); Bagger, Fontaine, Postel-Vinay, and Robin (2014); Lise, Meghir and Robin (2016); and Lise and Robin (2017).

• **Job and worker turnover decisions interdependent with training investments:** Cairo (2013); Cairo and Kajner (forthcoming); Flinn, Gemici, and Laufer (2017); Lentz and Roys (2015)

• **Stylized facts on job turnover, skill premium, relation to tradability of products:** Hyatt and Spletzer (2012); Decker, Haltiwanger, Jarmin, and Miranda (2016); Davis and Haltiwanger (2014); Cairo and Cajner (2015); Haltiwanger, Hyatt, and McEntarfer (2017); Autor and Dorn (2013); Jensen and Kletzer (2006); Kletzer (2007); Autor, Dorn, and Hanson (2013); Autor, Dorn, Hanson, and Song (2014); etc.
• Output producers bundle specific tasks, some of which can be accomplished offshore and embodied in intermediate goods trade: Grossman and Rossi-Hansberg (2008); Eaton, Kortum, and Kramartz (2017).


• Globalization affects the skill distribution by changing the worker-specific returns to human capital investment: Cosar (2013); Davidson and Sly (2014); and Blanchard and Willmann (2016).

• **Quantify barriers to worker mobility across sectors and/or occupations:** Lee and Wolpin (2006, 2010); Cosar (2013); Artuc, Chaudhuri, and McClaren (2014, 2016); Dix-Carneiro (2014); Caliendo, Dvorkin, and Parro (2016); Lee (2016); and Traiberman (2017).

• **Life cycle earnings trajectories:** Cosar (2013), Autor, Dorn and Hanson (2015), Kong, Ravikumar and Vandenbroucke (2018), Lagakos, Moll, Porzio, Qian, and Schoellman (2018)
J2J transitions and import penetration

\[ 1_{jt}^{j2j} = \beta \cdot \text{imp}_{o(it)} + \delta \cdot \text{brain}_{o(it)} + \zeta \cdot X_{it} + \eta_t + \nu_{s(it)} + \epsilon_{it} \]

<table>
<thead>
<tr>
<th>Time period</th>
<th>89-95</th>
<th>96-03</th>
<th>04-07</th>
<th>08-13</th>
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<tr>
<td>\text{imp}_{o(it)}</td>
<td>-0.004***</td>
<td>-0.009***</td>
<td>-0.0128***</td>
<td>-0.0131***</td>
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<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.004)</td>
<td>(0.002)</td>
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<td>1,215,022</td>
<td>408,378</td>
<td>996,730</td>
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\text{imp}_{o(it)} : employment share-weighted import penetration rate, occupation \( o \)

\( X_{it} \): gender, race, married, state, metropolitan city, \# kids, disability, union affiliation, multiple jobs

\( \eta_t, \nu_{s(it)} \) time and sector fixed effects
Occupation-specific changes in training rates
1990-2000 and 2000-2010

\[ \Delta \text{train}_{jt} = \beta \cdot \Delta \text{imp}_{jt} + \zeta \cdot X_{jt} + \eta_j + \upsilon_t + \epsilon_{jt} \]

<table>
<thead>
<tr>
<th>( \Delta \text{imp}_{jt} )</th>
<th>(1) (-4.96^{**})</th>
<th>(2) (-8.93^{**})</th>
<th>(3) (-4.14^{**})</th>
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<td>controls</td>
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<td>yes</td>
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<tr>
<td>( R^2 )</td>
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<tr>
<td>Observations</td>
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<td>198</td>
<td>198</td>
</tr>
</tbody>
</table>

\( \text{imp}_{jt} \): employment share-weighted import penetration rate, occup. \( j \)

\( X_{jt} \): share female, share white, share college-educated, brain indicies, brawn indicies
Why have a task producing sector?

- Need poaching and search frictions to help drive wage trajectories.
- If goods producers hired multiple types of workers directly, wage bargaining would become impossibly complex.
- Competitive market for tasks divorces effects of hiring frictions from producers’ factor proportions decisions.

Think of human resource departments as independent task-producing firms

- View the earnings of human resource personnel as reflective of the vacancy posting costs incurred by task-producing firms.
- View profits of the task-producing firms as the operating profits of goods producers in excess of capital costs. (No product market mark-ups.)
- Similar in spirit to literature linking labor’s share to employer’s monopsony power.
The environment: goods producing firms

- Each produces a product variety \( \omega \) specific to sector \( k \): \( \omega \in \Omega_k \), \( k \in \{1, \ldots, K\} \)
- Combines bundles of labor services (\( \tilde{y}_{k, \omega}^k \)) and bundles of product varieties (\( x_{k, \omega}^k \)) to generate output (\( q_{k, \omega} \)).

\[
q_{k, \omega} = e_{k, \omega} \left( \frac{\tilde{y}_{k, \omega}}{\alpha_k} \right)^{\alpha_k} \prod_{\tilde{k}=1}^{K} \left( \frac{x_{\tilde{k}, \omega}^k}{(1 - \alpha_k) \vartheta_{k, \tilde{k}}} \right)^{(1-\alpha_k) \vartheta_{k, \tilde{k}}}
\]

- Bundles of labor services and of varieties \( \tilde{\omega} \in \Omega_{\tilde{k}} \) are CES aggregations.

\[
x_{k, \omega} = \left[ \int_{\tilde{\omega} \in \Omega_{\tilde{k}}} \left( x_{k, \omega}^{\tilde{k}} \right)^{\eta_{\tilde{k}}^{-1}} \eta_k \right]^{\eta_k^{-1}} d\tilde{\omega},
\]

\[
\tilde{y}_{k, \omega} = \prod_{j=1}^{J} \left( \frac{y_{k, \omega}^j}{\mu_k^j} \right)^{\mu_k^j}, \quad \mu_k^j \geq 0, \quad \sum_j \mu_k^j = 1
\]
• Wage setting with on-the-job search related to Mortensen (2010), Bagger et al. (2014), Lise et al. (2016)

• Define:
  
  • \( S_E(a, j, z) \): match surplus when a type-(E, a) worker meets a type-j firm in productivity state \( z \)
  
  • \( J^e_E(wu, a, j, z) \): value of the job to the worker
  
  • \( J^u_E(a) \): value of unemployed state.

• For workers hired out of unemployment, the negotiated wage solves:

\[
J^e_E(wu, a, j, z) - J^u_E(a) = \beta S_E(a, j, z)
\]
Encounters with potential poachers

Suppose type-($E, a$) worker at a type-($j, z$) firm discovers a vacandy at a type-($\tilde{j}, \tilde{z}$) firm. Possible outcomes:

- **Surplus bigger at potential poaching firm:** $S_E(a, \tilde{j}, \tilde{z}) \geq S_E(a, j, z)$. Worker moves and receives wage that solves

$$J^e_E(w_o, a, \tilde{j}, \tilde{z}) - J^u_E(a) = \beta S_E(a, \tilde{j}, \tilde{z})$$

Poaching firm has no effect on worker's wage: $w_o = w$.
Encounters with potential poachers

Suppose type-$(E, a)$ worker at a type-$(j, z)$ firm discovers a vacandy at a type-$(\tilde{j}, \tilde{z})$ firm. Possible outcomes:

- **Surplus bigger at potential poaching firm:** $S_E(a, \tilde{j}, \tilde{z}) \geq S_E(a, j, z)$. Worker moves and receives wage that solves

  $$J_E^e(w_o, a, \tilde{j}, \tilde{z}) - J_E^u(a) = \beta S_E(a, \tilde{j}, \tilde{z})$$

- **Surplus less at potential poaching firm:** $S_E(a, \tilde{j}, \tilde{z}) < S_E(a, j, z)$. Poaching firm has no effect on worker’s wage:

  $$w_o = w$$
Productivity shocks

- **Productivity shock destroys match surplus:** $S_E(a, j, z') < 0$
  Worker reverts to unemployed state:
  
  \[ w_\varphi = b_E \]
Productivity shocks

- **Productivity shock destroys match surplus:** \( S_E(a, j, z') < 0 \).
  Worker reverts to unemployed state:
  \[ w_\varphi = b_E \]

- **Productivity shock doesn’t destroy match surplus:** \( S_E(a, j, z') \geq 0 \).
  Worker renegotiates wage:
  \[ J^e_E(w_\varphi, a, j, z') - J^u_E(a) = \beta S_E(a, j, z') \]
Productivity shocks

- **Productivity shock destroys match surplus:** \( S_E(a, j, z') < 0 \). Worker reverts to unemployed state:
  \[
  w_\varphi = b_E
  \]

- **Productivity shock doesn’t destroy match surplus:** \( S_E(a, j, z') \geq 0 \). Worker renegotiates wage:
  \[
  J^e_E(w_\varphi, a, j, z') - J^u_E(a) = \beta S_E(a, j, z')
  \]

- **Exogenous separation shock:** Worker reverts to unemployed state:
  \[
  w_\varphi = b_E
  \]
• **Shock destroys match surplus:** \( S_E(a', j, z) < 0 \). Worker reverts to unemployed state:

\[
   w_\varphi = b_E
\]
Ability shocks

- **Shock destroys match surplus:** \( S_E(a', j, z) < 0 \). Worker reverts to unemployed state:
  \[
  w_\varphi = b_E
  \]

- **Shock doesn’t destroy match surplus:** \( S_E(a', j, z) \geq 0 \). Worker renegotiates wage:
  \[
  J^e_E(w_\varphi, a', j, \tilde{z}) - J^u_E(a') = \beta S_E(a', j, \tilde{z})
  \]
[\rho + \delta \ell] J^e_E(a, j, z) =

w + \delta_f [J^u_E(i) - J^e_E(a, j, z)]

+ \varphi \sum_{\tilde{z} \in \mathcal{Z}} \max\{J^e_E(a, j, \tilde{z}) - J^e_E(a, j, z),
J^u_E(a) - J^e_E(a, j, z)\} \Lambda(\tilde{z}|z)

+ \gamma_E(a, j, z) \max\{J^e_E(a', j, z) - J^e_E(a, j, z),
J^u_E(a') - J^e_E(a, j, z)\}

+ \sum_{\tilde{j} \in \mathcal{J}} \phi^\ell_{j, \tilde{j}} \sum_{\tilde{z} \in \mathcal{A}_E(j, z, i|\tilde{j})} [J^e_E(a, \tilde{j}, \tilde{z}) - J^e_E(a, j, z)] v_{\tilde{j}}(\tilde{z})
$[\rho + \delta_f] \Pi_E^e(w, a, j, z) =$

$r_j y_E(a, j, z) - c^0 - w + \delta_{ij} [\Pi^v(j, z) - \Pi_E^e(a, j, z)]$

$+ \varphi \sum \max\{\Pi_E^e(a, j, \tilde{z}) - \Pi_E^e(a, j, z), \Pi^v(j, \tilde{z}) - \Pi_E^e(a, j, z)\} \Lambda(\tilde{z}|z)$

$+ \gamma_E(a, j, z) \max\{\Pi_E^e(a', j, z) - \Pi_E^e(a, i, z), \Pi^v(j, z) - \Pi_E^e(a, j, z)\}$

$+ \sum_{\tilde{j} \in S} \phi_{j, \tilde{j}} \sum_{\tilde{z} \in A_E(j, z, i|\tilde{j})} [\Pi^v(j, z) - \Pi_E^e(a, j, z)] v_{j}(\tilde{z})
value of being unemployed:

\[
[\rho + \delta_{\ell}] J_E^u(a) = b_E + \beta \sum_{j \in S} \sum_{z \in Z} \max\{S_E(a, j, z), 0\} v_j(z).
\]

value of vacancy:

\[
(\rho + \delta_f) \Pi^v(j, z)
= -c^v + (1 - \beta) \phi^f_{j,0} \sum_{E \in \{L,H\}} \sum_{a \in A} \max\{S_E(a, j, z), 0\} g_E(a)
+ (1 - \beta) \sum_{E \in \{L,H\}} \sum_{a \in A} \sum_{j \in S} \sum_{\tilde{z} \in A_E(j,z,i|\tilde{j})} S_E(a, j, z) n_E^j(a, \tilde{z})
\]
J-to-J by brain skill (Data)

Slope: -0.451 (0.086) - Corr: -0.708

"Brain" Skill Content

job to job transition rate, %

-1.5 -0.75 0 0.75 1.5

1 1.5 2 2.5 3 3.5 4

1.5 2 2.5 3 3.5 4
E-to-U by brain skill (Data)

Slope: -0.744 (0.103) - Corr: -0.804
Market clearing conditions

- Clearing in product markets:

\[ X^n_k = \sum_{k=1}^{K} (1 - \alpha^n_k) \theta^n_{kk} \sum_{\tilde{n}=1}^{N} \frac{\pi^n_{\tilde{n}, n} X^n_{\tilde{n}}}{1 + \tau^n_{\tilde{n}, n}} + \nu_k I^n \]

\[ I^n = Y^n + T^n + D^n \]

\[ T^n = \sum_{k=1}^{K} \sum_{\tilde{n}=1}^{N} \frac{\pi^n_{k, \tilde{n}} X^n_{k}}{1 + \tau^n_{k, \tilde{n}}} \tau^n_{\tilde{n}, n} X^n_k \]

\[ D^n = \sum_{k=1}^{K} \sum_{\tilde{n}=1}^{N} \frac{\pi^n_{k, \tilde{n}} X^n_{k}}{1 + \tau^n_{k, \tilde{n}}} X^n_{\tilde{n}} \]

- Clearing in task markets:

\[ Y^n_j = \sum_{k=1}^{K} \mu^n_{jk} \frac{\tilde{r}_k}{r_j} \frac{\alpha^n_k}{\tilde{r}_k} X^n_k = N_j \sum_{E \in \{L, H\}} \sum_{i \in I} \sum_{z \in Z} y_E(j, z, i) f_E(j, z, i) \]

\{demand\} \hspace{2cm} \{supply\}
• Free entry condition for task-producing firms

\[ \sum_{z \in Z} \Pi^v(j, z) \Lambda^e(z) \leq 0, \quad F_j \geq 0, \quad \forall j \in J \]

• Flow balance of task-producing firms across states

\[ F_{jz} \left[ \delta_f + \varphi \sum_{\tilde{z} \in \mathcal{Z}/z} \Lambda(\tilde{z}|z) \right] = \varphi \sum_{\tilde{z} \in \mathcal{Z}} \Lambda(z|\tilde{z}) F_{j\tilde{z}} + \Lambda^e(z) F^e_j \quad \forall z \in \mathcal{Z}, \forall j \in J \]

\begin{itemize}
  \item outflows + exit
  \item inflows
  \item new entrants
\end{itemize}
Flows of task-producing firms-workers matches

\[
\gamma_E(j, z, i - 1) N_{Ej} f_E(j, z, i - 1) + \varphi \sum_{\bar{z} \in \mathcal{Z}} \Lambda(z | \bar{z}) N_{Ej} f_E(j, \bar{z}, i)
\]

inflows due to training updates

\[
\sum_{\tilde{j} \in S} \tilde{\phi}_{\tilde{j}j} N_{E\tilde{j}} \sum_{\bar{z} \in \mathcal{C}_1(\tilde{j}, z, i|j)} n_E(\tilde{j}, \bar{z}, i)
\]

inflows due to productivity change

\[
\delta_w + \delta_f + \varphi \sum_{\bar{z} \in \mathcal{Z}/z} \Lambda(\bar{z} | z) + \gamma_E(j, z, i) + \sum_{\tilde{j} \in S} \tilde{\phi}_{j\tilde{j}} \sum_{\bar{z} \in \mathcal{C}_2(j, z, i|\tilde{j})} v_{E\tilde{j}}(\bar{z})
\]

inflows due to new hirings

\[
N_{Ej} f_E(j, z, i)
\]

outflows
Flows of workers across states

\[ U_{EI}[\delta w + \sum_{j \in J} \sum_{z \in Z} \tilde{\phi}_{0,j} \sum_{z \in Z} 1\{S_E(j,z,i) \geq 0\} V_{Ej}(z)] = \delta_f \sum_{j \in J} \sum_{z \in Z} N_{Ejzi} + \varphi \sum_{j \in S} \sum_{z \in Z} N_{Ejzi} \sum_{\tilde{z} \in Z} 1\{S_E(j,\tilde{z},i) < 0\} \Lambda(\tilde{z}|z) + \left. L^e_{EI} \right|_{\text{new entrants}}. \]
Australia, Austria, Brazil, Canada, Chile, China, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Turkey, UK, USA, ROW.
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<td>3</td>
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<td>Wood and Product of Wood and Cork</td>
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<td>Financial Intermediation</td>
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<td>Health and Social Work</td>
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<td>OtP</td>
<td>Other Community, Social, Personal Services</td>
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Table: **List of 1-digit SOC occupations**

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<thead>
<tr>
<th>Code</th>
<th>1-digit SOC</th>
<th>Description</th>
<th>Brain-content</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>Production, Transportation, and Material Moving Occupations</td>
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<tr>
<td>2</td>
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<td>Natural Resources, Construction, and Maintenance Occupations</td>
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<td>3</td>
<td>31-39</td>
<td>Service Occupations</td>
<td>0.134</td>
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<tr>
<td>4</td>
<td>41-43</td>
<td>Sales and Office Occupations</td>
<td>0.236</td>
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<tr>
<td>5</td>
<td>11-29</td>
<td>Management, Business, Science, and Arts Occupations</td>
<td>1</td>
</tr>
</tbody>
</table>

Table: **Distance matrix between 1-digit 2002 SOC occupations**

<table>
<thead>
<tr>
<th></th>
<th>11-29</th>
<th>31-39</th>
<th>41-43</th>
<th>45-49</th>
<th>51-53</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-29</td>
<td>0</td>
<td>10.18</td>
<td>8.25</td>
<td>12.43</td>
<td>12.90</td>
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<tr>
<td>31-39</td>
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<td>0</td>
<td>2.84</td>
<td>3.12</td>
<td>3.26</td>
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<tr>
<td>41-43</td>
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<td>0</td>
<td>5.84</td>
<td>5.96</td>
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<tr>
<td>45-49</td>
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<td>3.12</td>
<td>5.84</td>
<td>0</td>
<td>0.75</td>
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<tr>
<td>51-53</td>
<td>12.90</td>
<td>3.26</td>
<td>5.96</td>
<td>0.75</td>
<td>0</td>
</tr>
</tbody>
</table>
Distance measures

Visibility: \( \lambda_{j,\tilde{j}} = \frac{\lambda}{[1 + d(j,\tilde{j})]^\xi} \), where

\[
d(j,\tilde{j}) = \sqrt{\left( \mathbf{v}_j - \mathbf{v}_{\tilde{j}} \right)' \Sigma^{-1} \left( \mathbf{v}_j - \mathbf{v}_{\tilde{j}} \right)}
\]