Unbundling Labor

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RA: Alex Weinberg

This paper

- Has technological change made jobs more or less similar?
- What are the implications for wage inequality?
- When does such technological change arise?

1970 - Cafe





2020 - Starbucks





This paper

1. Facts

A. Skill requirement heterogeneity across occupations

↓ Low skill jobs , ↑ High skill jobs

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- Technological change consistent with **A.** causes **B.**
- Extend Rosen (1983), Heckman Scheinkman (1987)
- Endogenize **A.** as appropriate technology choice (Caselli Coleman, 2006)

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3. Extension

- Declining *experience premium* in low skill jobs
- Declining *overtime premium / part-time penalty* in low skill jobs
- Increasing *occupation switching* in low skill jobs

Fact A. - Technology

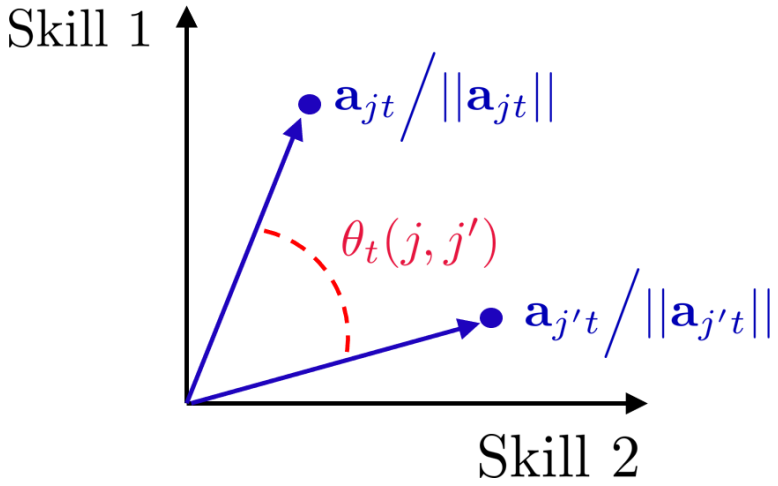
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Approach

1. O*NET data on 250+ skills and J occupations for 2003-09, 2010-18
2. Reduce to $4 \times J$ matrix of skills $\mathbf{A}_t = \left[\mathbf{a}_{1t}, \ldots, \mathbf{a}_{Jt}\right]$ (Lise Postel-Vinay, 2020)
3. Distance between occupations (Gathmann Schönberg, 2010)

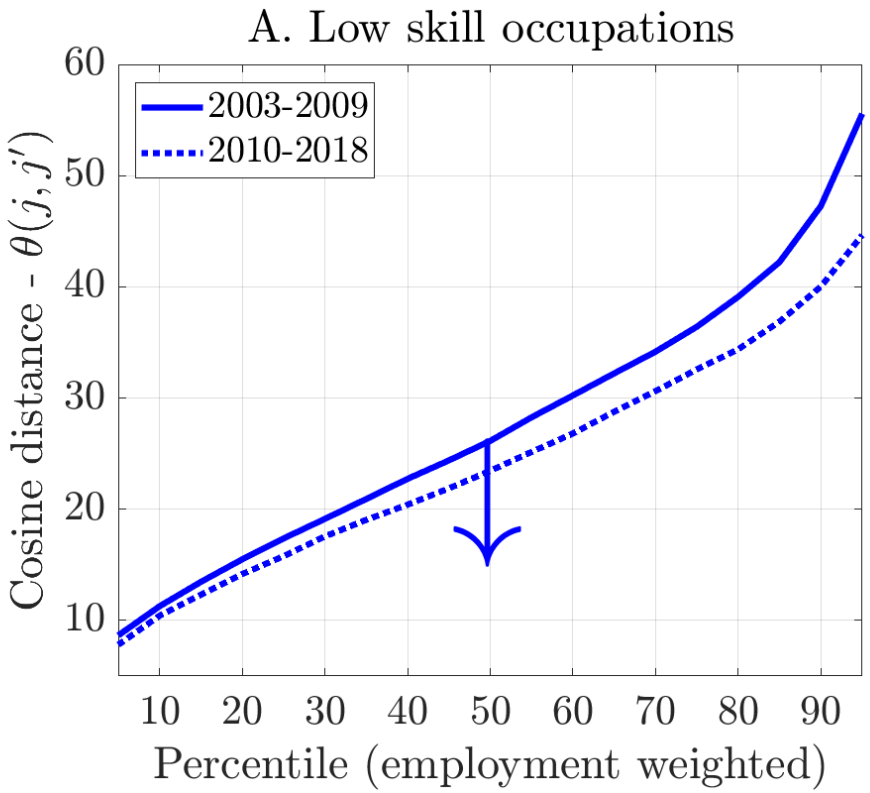


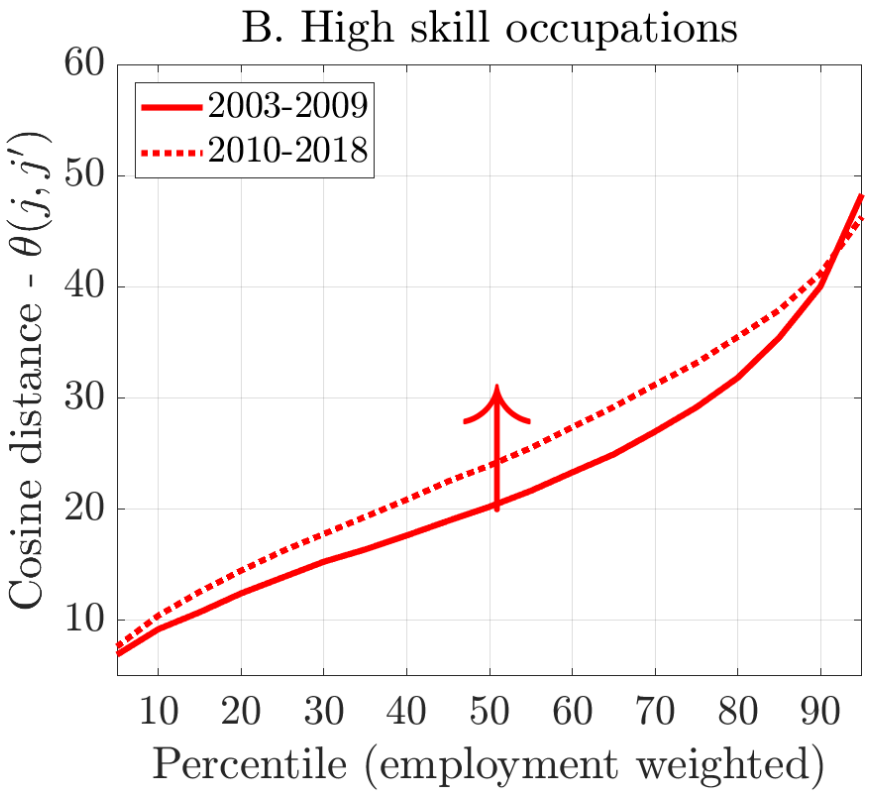
4. Compare the distribution of these distances $\theta_{j,j'}$ over time

▸ Details - Dimension reduction

Fact A. - Technology

Low skill (high skill) jobs have become more similar (more different)





Fact B. - Wages

Within low skill (high skill) jobs, wages are more similar (more different)

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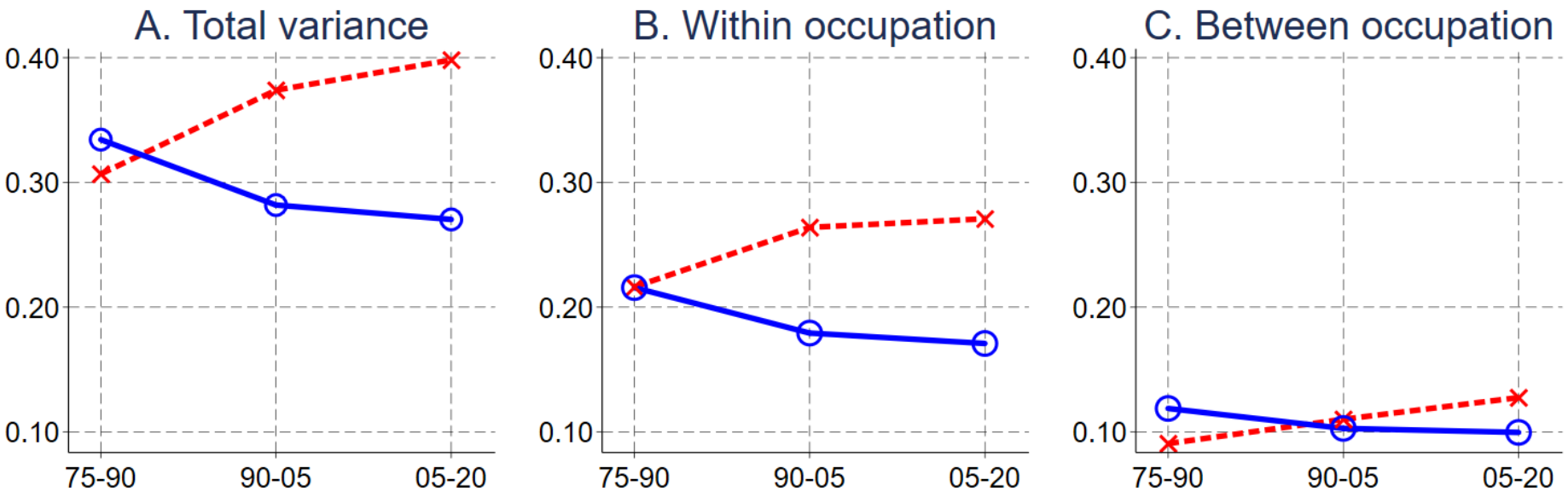
- Log annual earnings from the CPS
- Residuals e_{it} after controlling for observables

$$Year_t,\ NAICS1_{it},\ Ed_{it},\ Race_{it}\ ,Sex_{it}\ ,FirmSize_{it}\ ,Exp_{it}\ ,Exp_{it}^2\ ,Hours_{it}$$

- Estimate separately for Low and High skill occupations
- Estimate in 15 year windows
- Decompose $var\left(e_{it}\right)$ into within- and between-occupation variance

Fact B. - Wages

Within low skill (high skill) jobs, wages are more similar (more different)



Variance of residuals. Red = High wage occupations, Blue = Low wage occupations

Robust across {All,Male,Female}×{Fix occupations in 1980, 2010}

▸ Details

Model

- General equilibrium environment
  - Individual skills $l(i) = \left(l_A(i), l_B(i)\right)$
  - Two occupations $j \in \{1, 2\}$, with different skill intensities

- Competitive equilibrium wages

$$w_j(i) = \omega_{jA} l_A(i) + \omega_{jB} l_B(i) \quad \rightarrow \quad var\left(\log w_j(i) \middle| j\right)$$

- Within occupation inequality determined by two forces
  1. Distribution of skills conditional on selection
  2. Gradient of within-occupation skill prices $\{\omega_{jA}, \omega_{jB}\}$

Environment

- Workers $i \in [0,1]$ endowed with two skills $k \in \{A, B\}$

$$l(i) = \Big(l_A(i), l_B(i)\Big) \quad , \quad \Big(l_A(i), l_B(i)\Big) \sim H\Big(l_A, l_B\Big)$$

- Final good

$$U\Big(Y_1, Y_2\Big)$$

- Task / Occupation j technology:

$$Y_j = F_j\Big(L_{jA}, L_{jB}\Big) = Z_j\Big[\,\alpha_j L_{jA}^{\sigma} \quad + (1-\alpha_j)\, L_{jB}^{\sigma}\Big]^{\frac{1}{\sigma}} \quad , \quad \sigma < 1$$

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$$L_{jA} = \int l_A(i)\phi_j(i)\, di \;\; , \;\; L_{jB} = \int l_B(i)\phi_j(i)\, di \;\; , \;\; \phi_j(i) \in \{0,1\}$$

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BUNDLED - *Worker i must allocate $\Big(l_A(i), l_B(i)\Big)$ to the same task*

Mandelbrot (1962), Rosen (1983), Heckman Scheinkman (1987)

Efficient allocation

$$\max_{\phi_1(i)\in\{0,1\}} U\Big(F_1(L_{1A}, L_{1B}), F_2(L_{2A}, L_{2B})\Big)$$

subject to

$$\begin{aligned}
L_{1A} &= \int \phi_1(i)\, l_A(i)\, di \\
L_{2A} &= \int \Big[1 - \phi_1(i)\Big]\, l_A(i)\, di \\
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Efficient allocation

$$\max_{\phi_{1A}(i)\in\{0,1\},\phi_{1B}(i)\in\{0,1\}} U\Big(F_1(L_{1A},L_{1B}),F_2(L_{2A},L_{2B})\Big)$$

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and person-by-person bundling constraints

$$\phi_{1A}(i) = \phi_{1B}(i) \qquad \text{for all} \quad i \in [0,1]$$

Feasible allocations

- Replace continuum of individual constraints with a single constraint
- Given L_{1A} what is the *minimum* and *maximum* L_{1B} bundled with it?

$$\text{Bundling constraint:} \quad L_{1B} \in \left[\underline{B}(L_{1A}) \, , \, \overline{B}(L_{1A})\right]$$

- Construct L_{1A} using workers with highest $l_A(i) \big/ l_B(i)$ first

$$L_{1A} = \int_0^{i^*} l_A(i)\, di \quad , \quad \underline{B}(L_{1A}) = \int_0^{i^*} l_B(i)\, di$$

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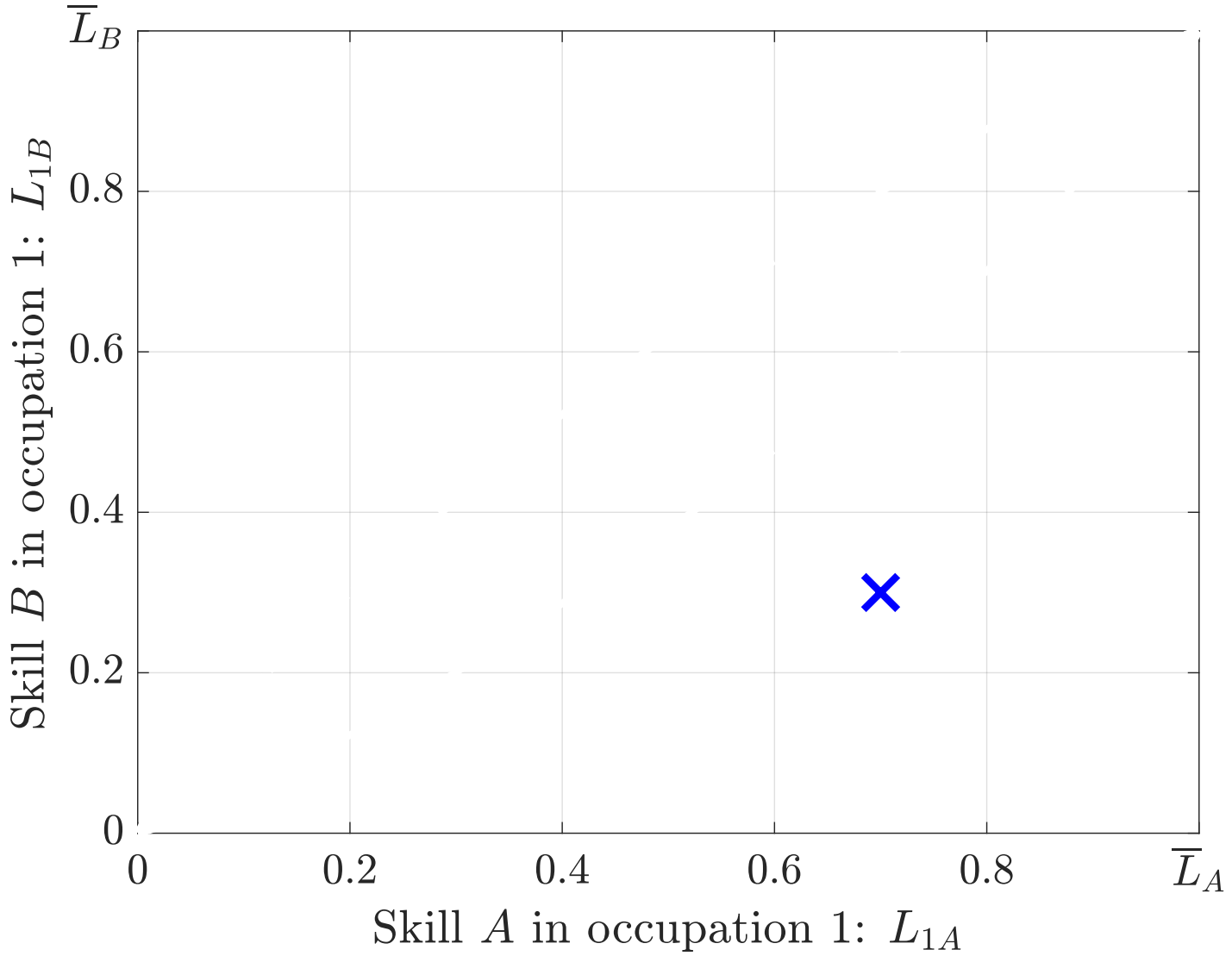
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Result - *If the skill distribution H has no mass points, then $\underline{B}$ ($\overline{B}$) is*

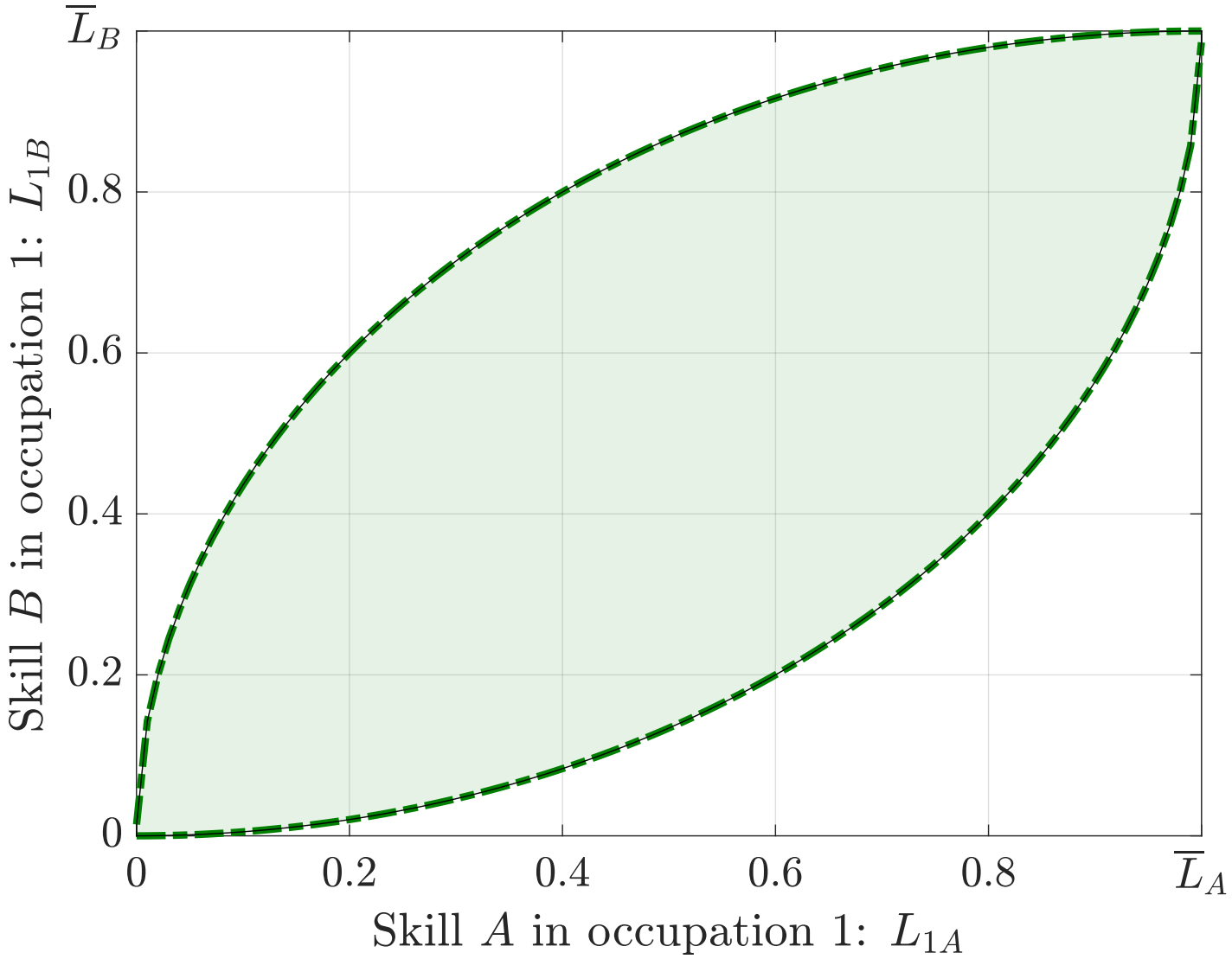
1. *Strictly increasing, strictly convex (concave)*
2. *Continuously differentiable* - $\underline{B}'(L_{1A}) = \dfrac{l_B(i^*)}{l_A(i^*)}$

Feasible allocations



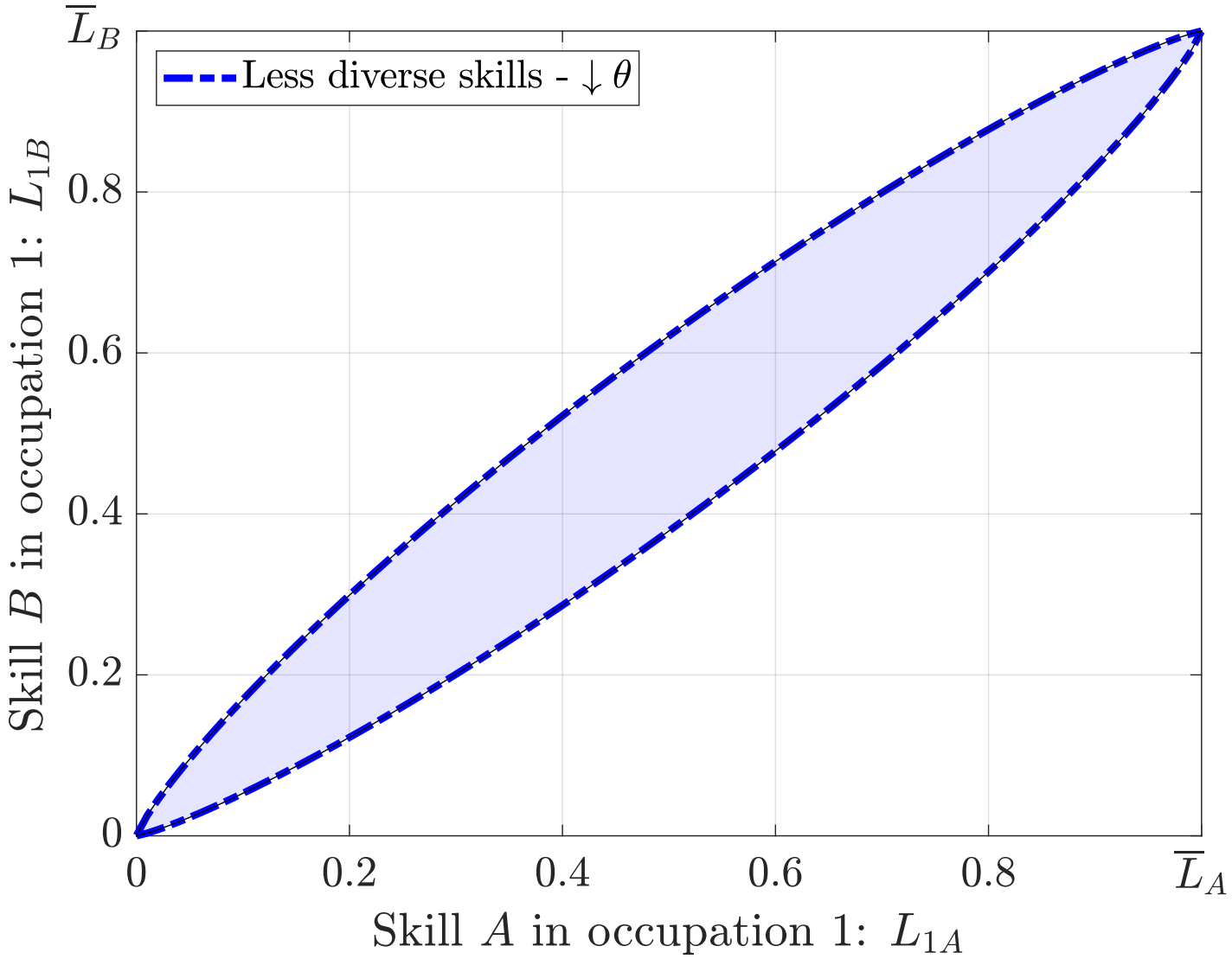
Feasible allocations

Feasible allocations must satisfy aggregate *bundling constraints* $L_{1B} \in [\underline{B}(L_{1A}), \overline{B}(L_{1A})]$.
Determined by distribution of skill endowments only. Example: $l_k(i) \sim$ *Fréchet*(θ).



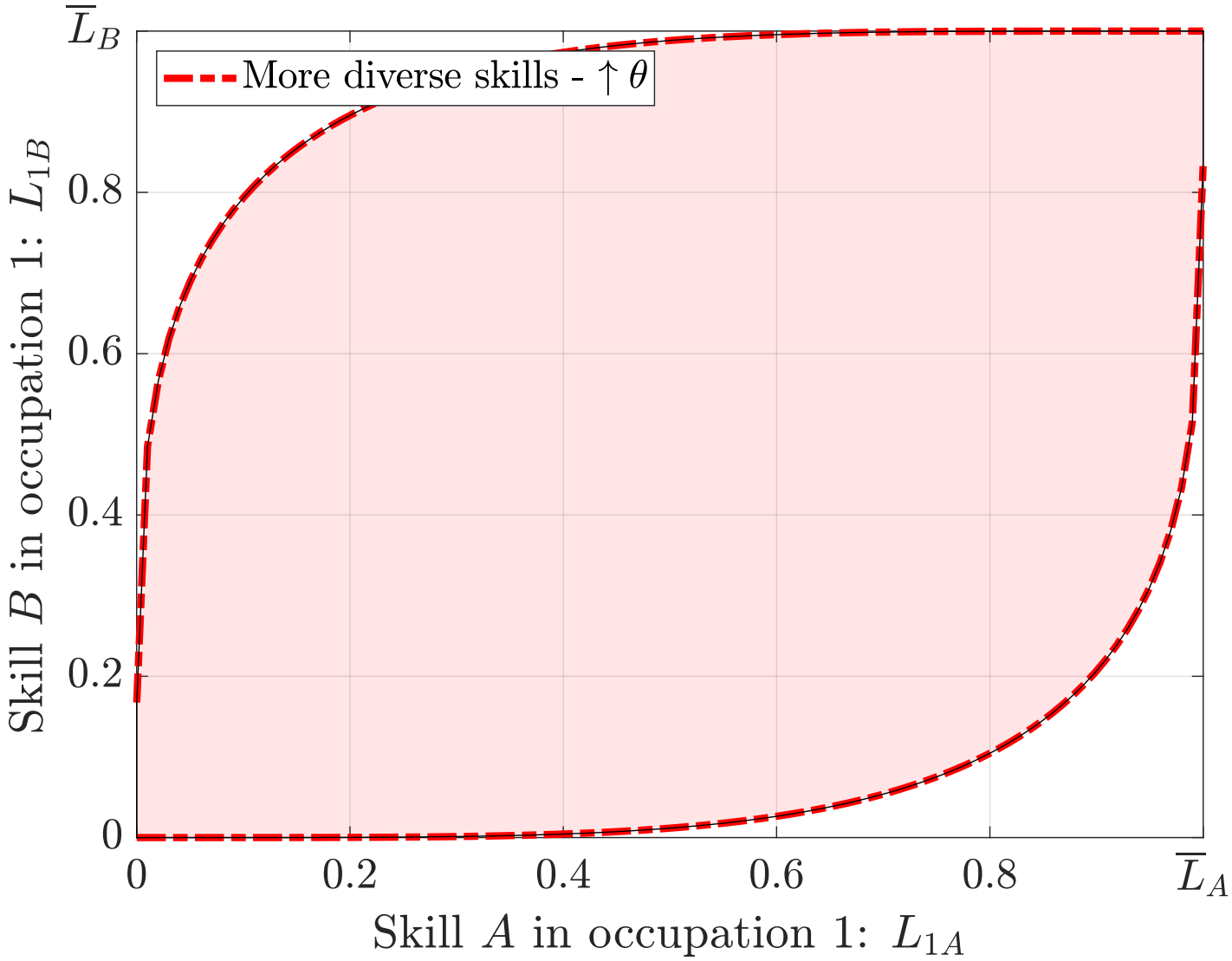
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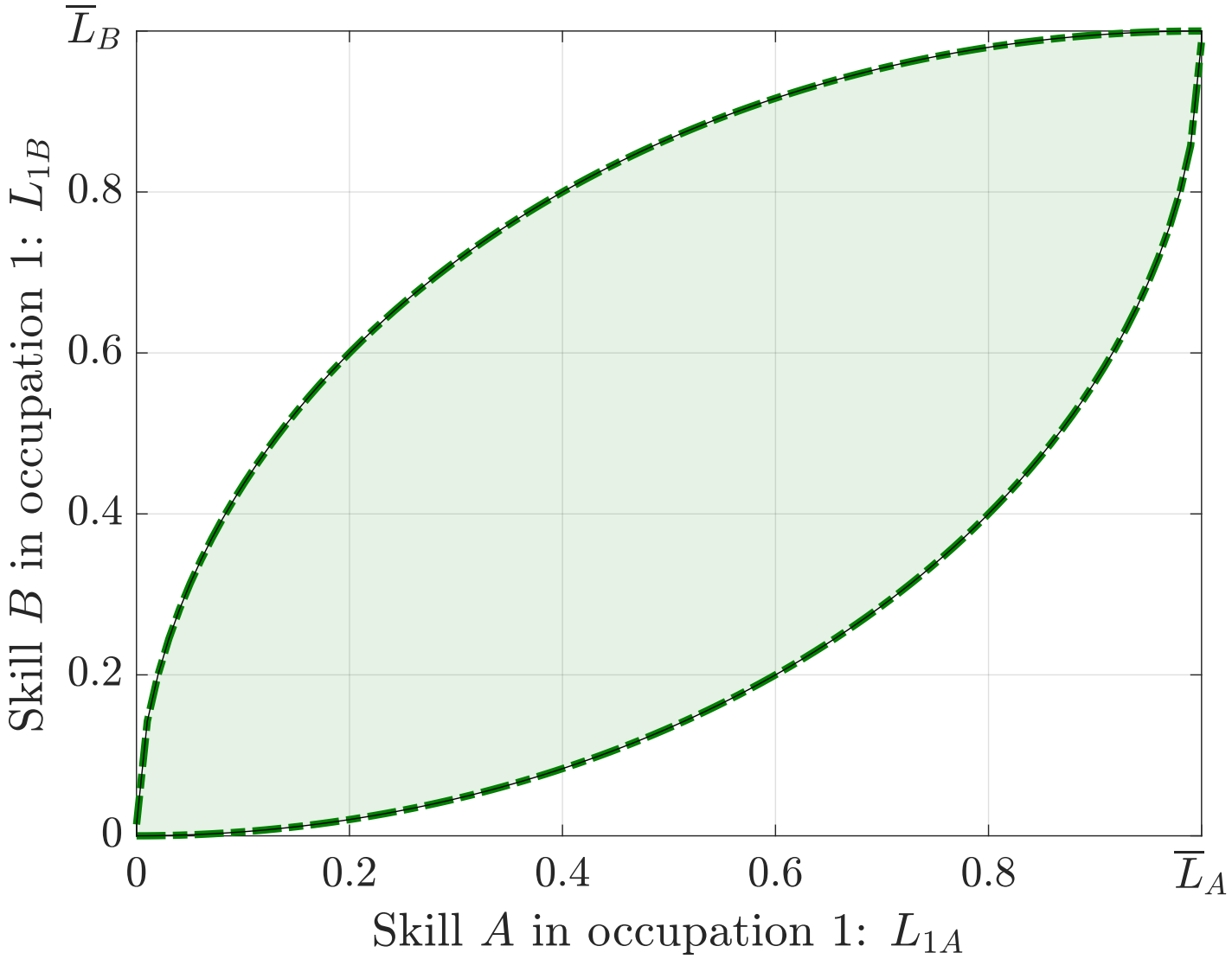
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subject to

$$\underbrace{L_{1B}\geq \underline{B}(L_{1A})}_{\text{Multiplier: } \underline{\beta}} \qquad \underbrace{L_{1B}\leq \overline{B}(L_{1A})}_{\text{Multiplier: } \overline{\beta}}$$

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First order conditions

$$\begin{aligned} L_{1A}: \quad \omega_{1A} &= \omega_{2A} + \underline{\beta}\,\underline{B}'(L_{1A}) \\ L_{1B}: \quad \omega_{1B} &= \omega_{2B} - \underline{\beta} \end{aligned}$$

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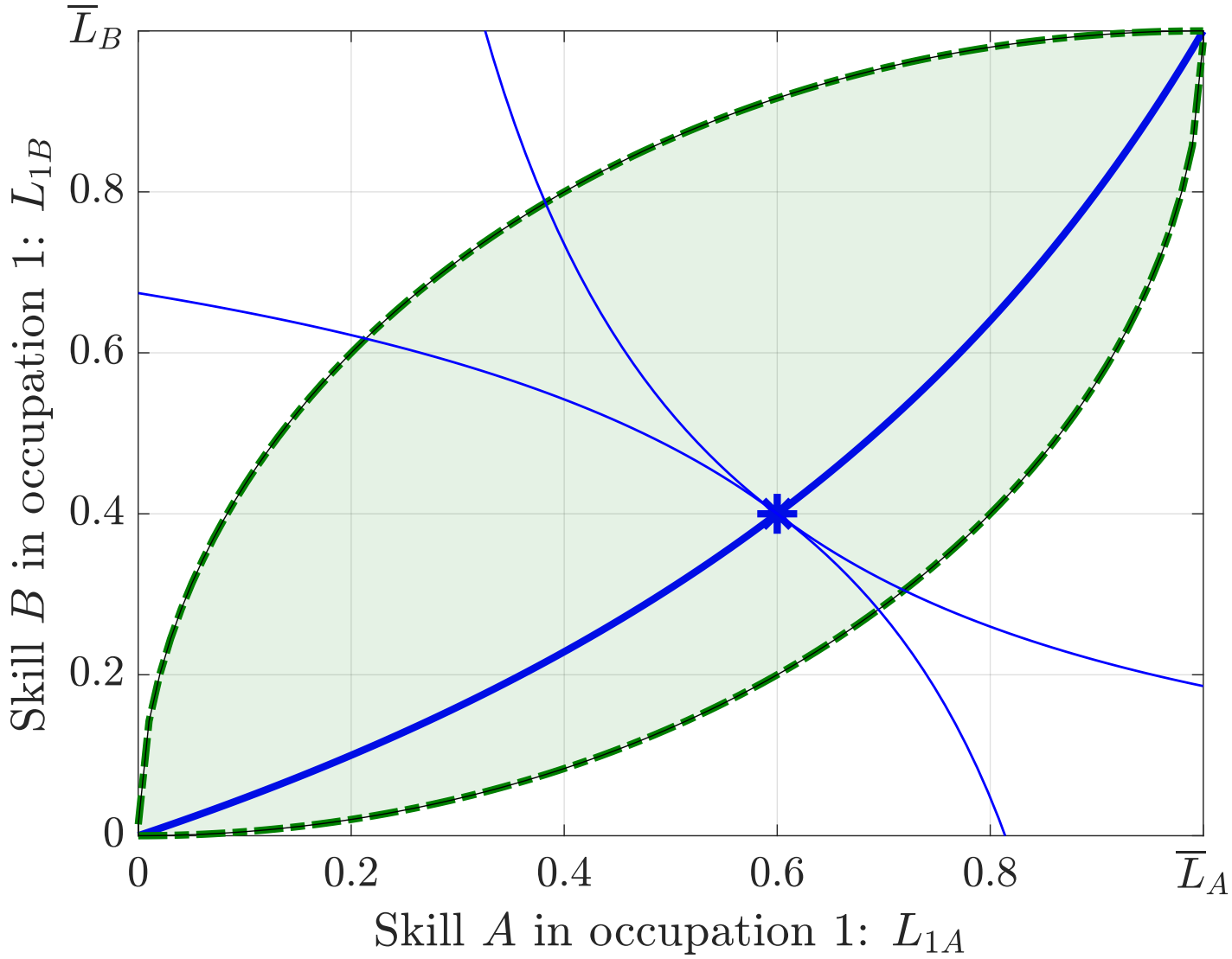
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Results

1. Same allocation as 'full' problem, 2. Decentralization
3. Comparative statics for $\underline{\beta}$ under Fréchet + Cobb-Douglas

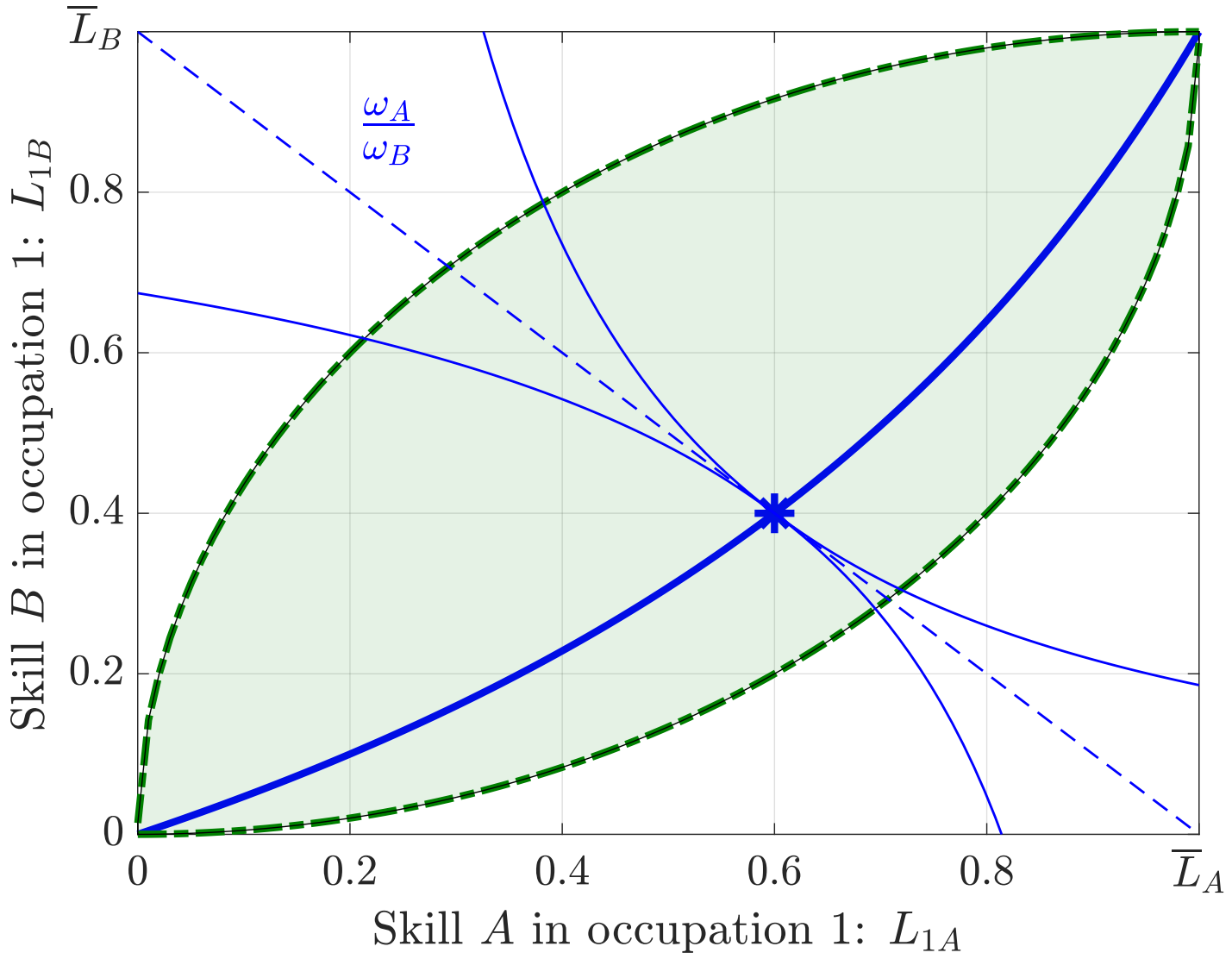
Unbundled allocation

'Contract curve' equates marginal rates of technical substitution: $F_{1A}/F_{1B} = F_{2A}/F_{2B}$.
Unbundled allocation equates U_1/U_2 to marginal rate of transformation F_{2k}/F_{1k}.



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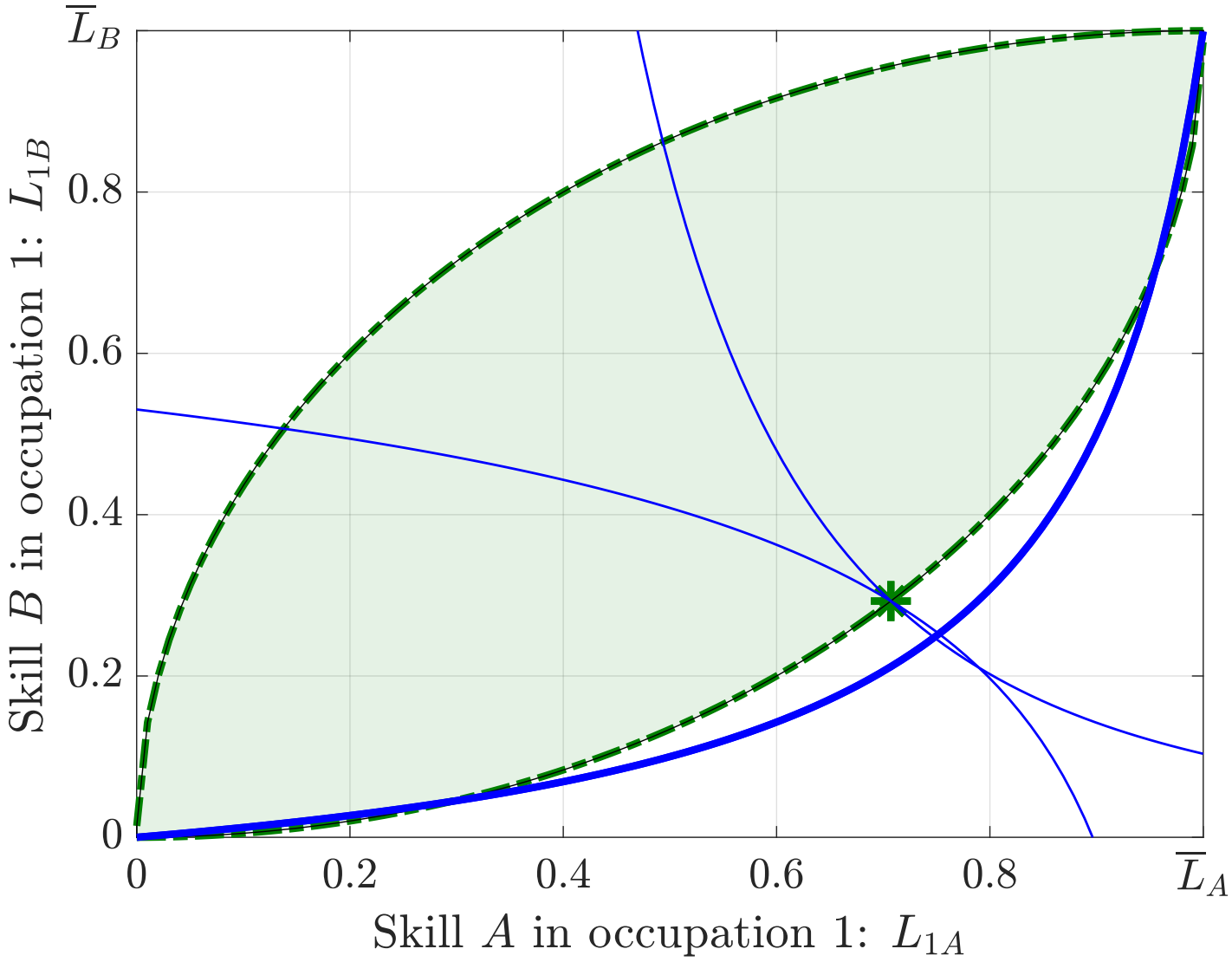
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Bundled allocation

Bundling constraint binds. Cannot 'break open' workers to get at underlying skill content.

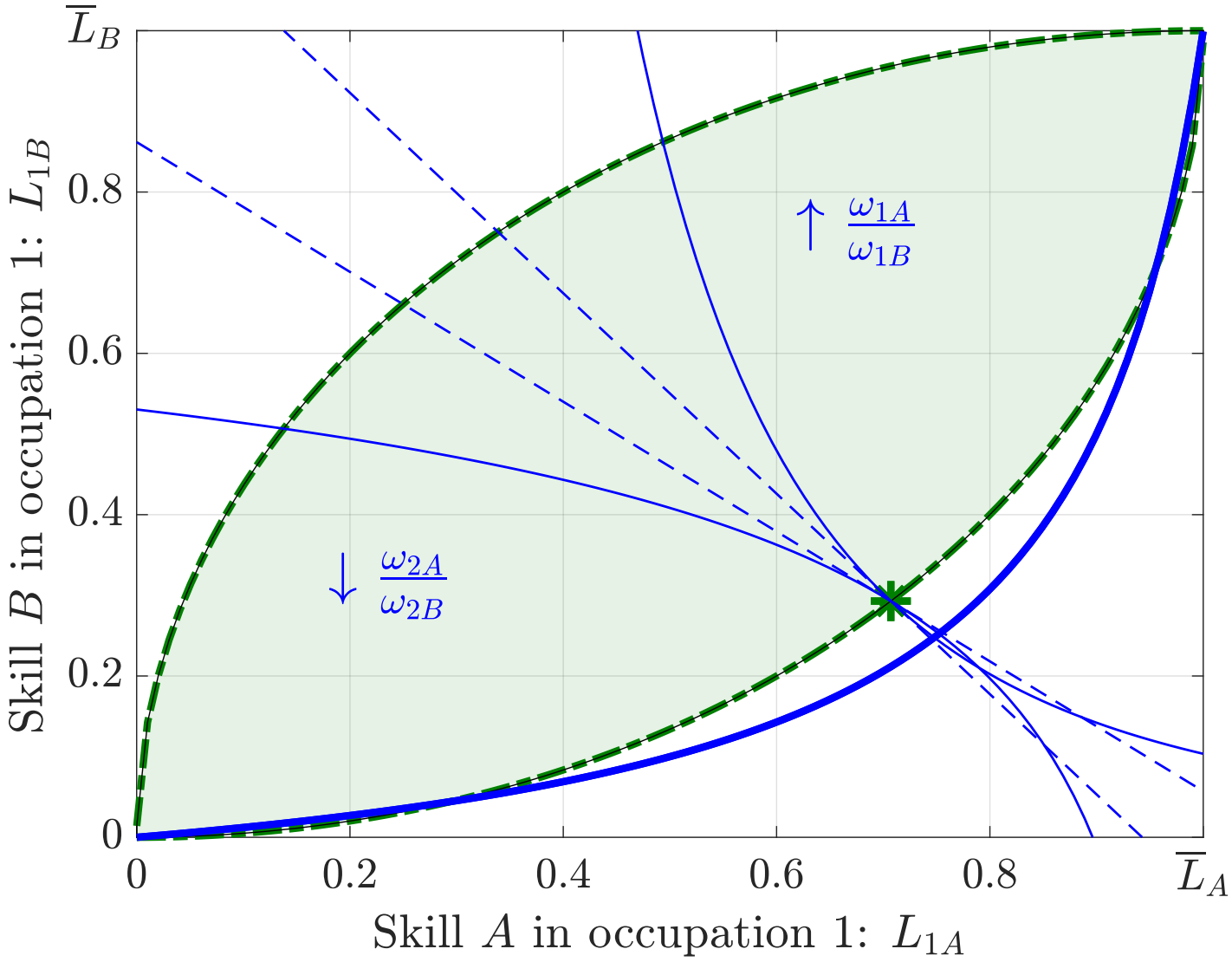
$$U_1\left[F_{1A} + \underline{B}'(L_{1A})F_{1B}\right] = U_2\left[F_{2A} + \underline{B}'(L_{1A})F_{2B}\right]$$



Bundled allocation

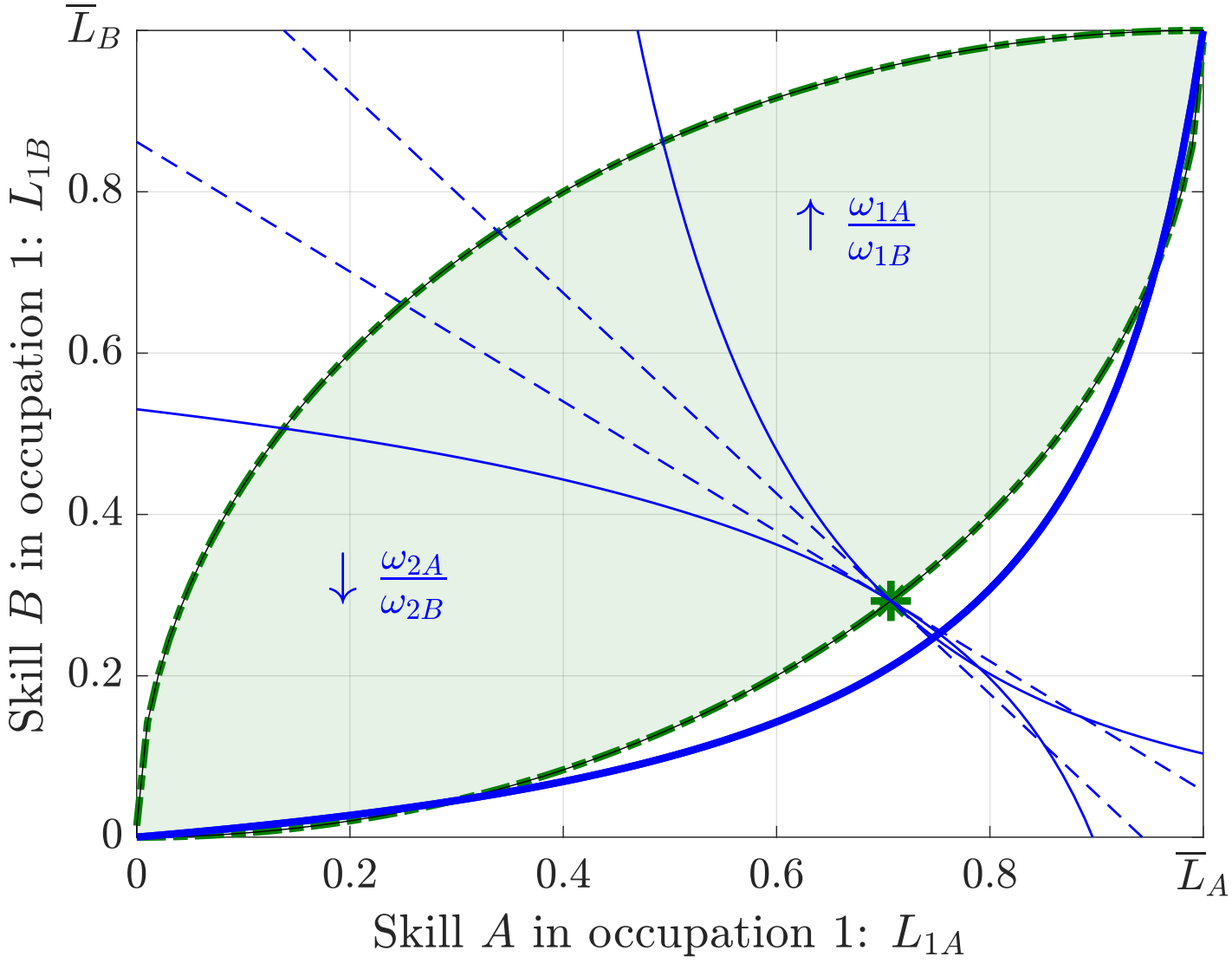
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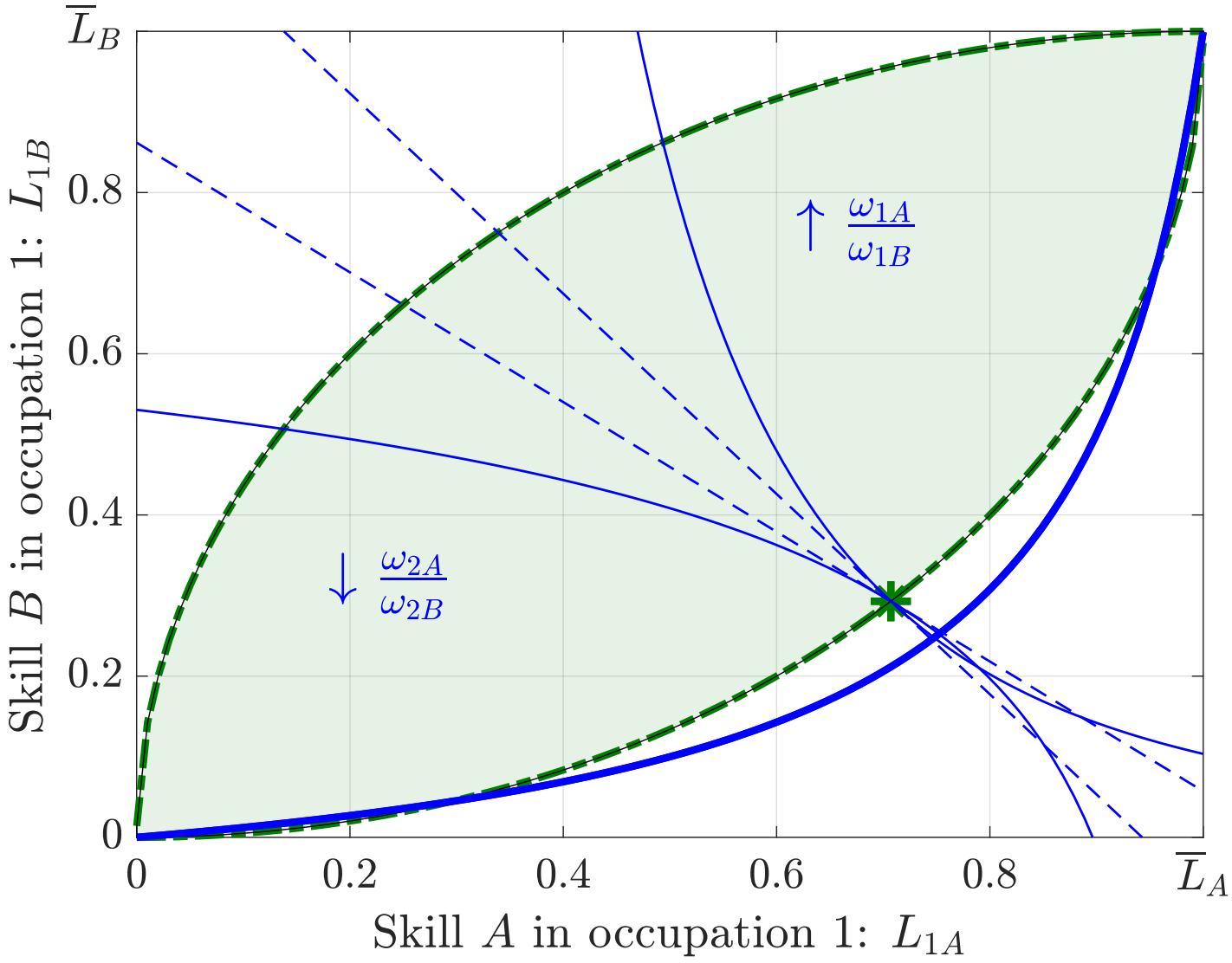
Wages

$$w_1(i) = \omega_{1A} l_A(i) + \omega_{1B} l_B(i)$$



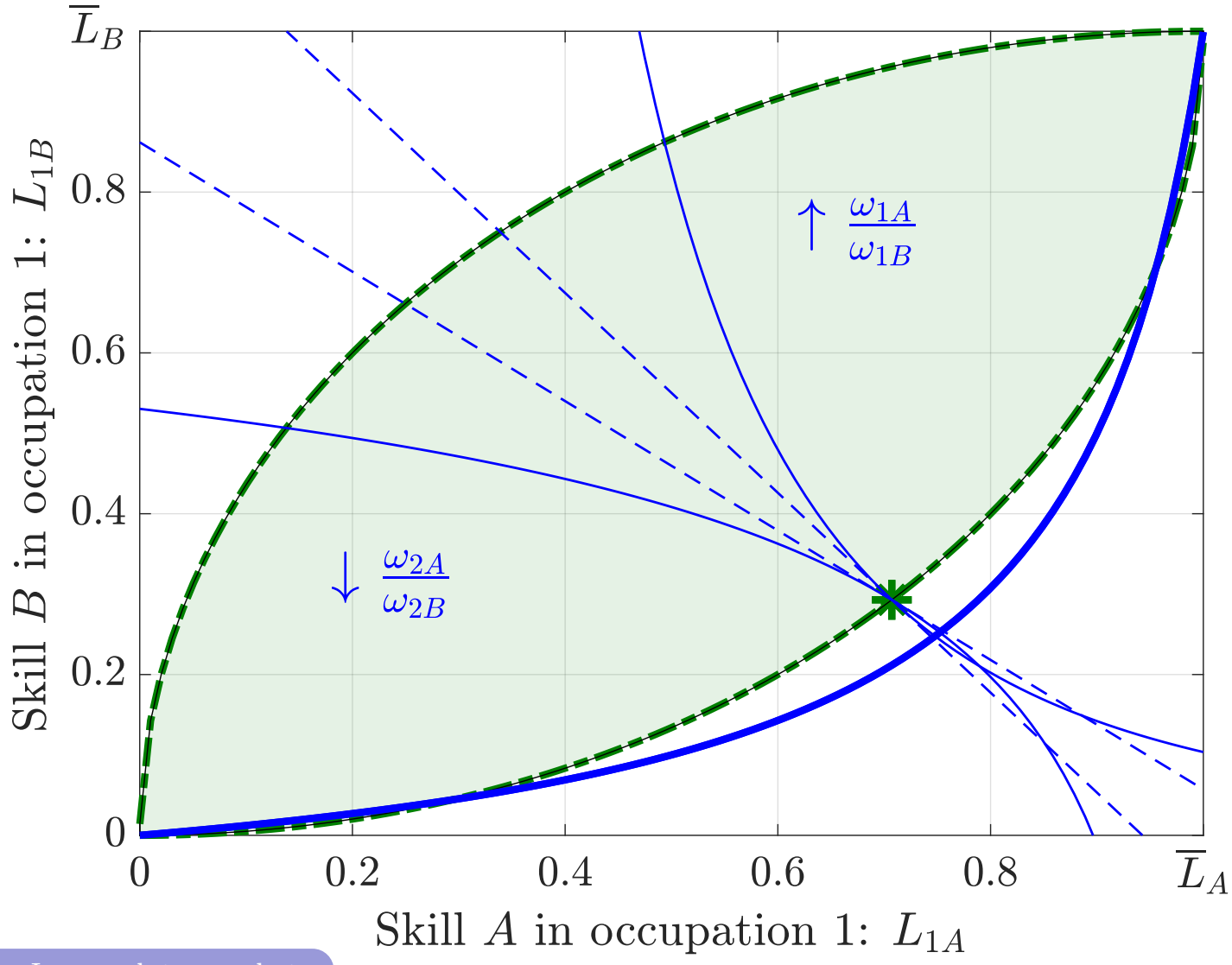
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$$w_1(i) = \left(1 + \left(\frac{\omega_{1A}}{\omega_{1B}}\right)\left(\frac{l_A(i)}{l_B(i)}\right)\right) \times \omega_{1B} l_B(i)$$



Wages

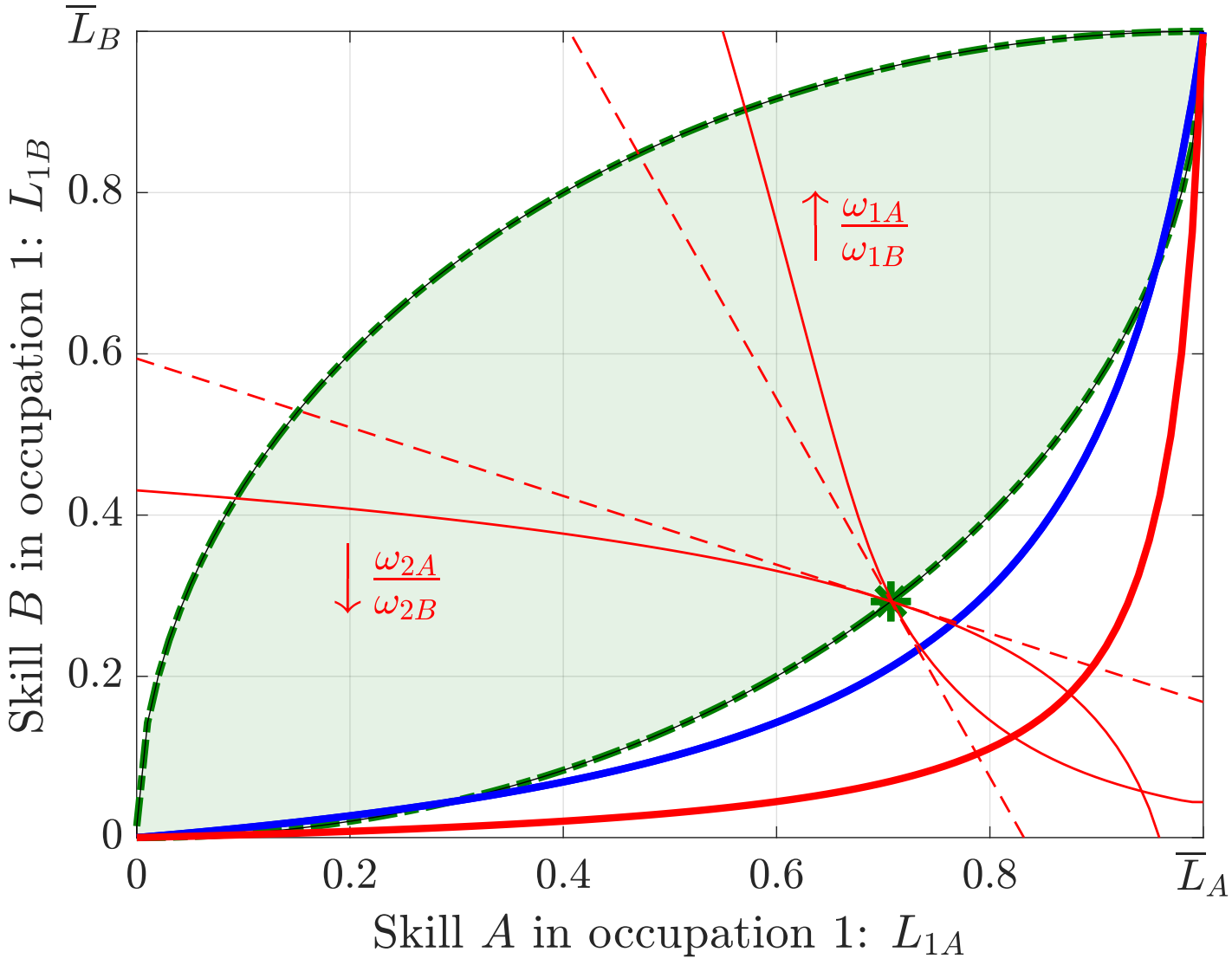
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▸ Aside - Incomplete markets

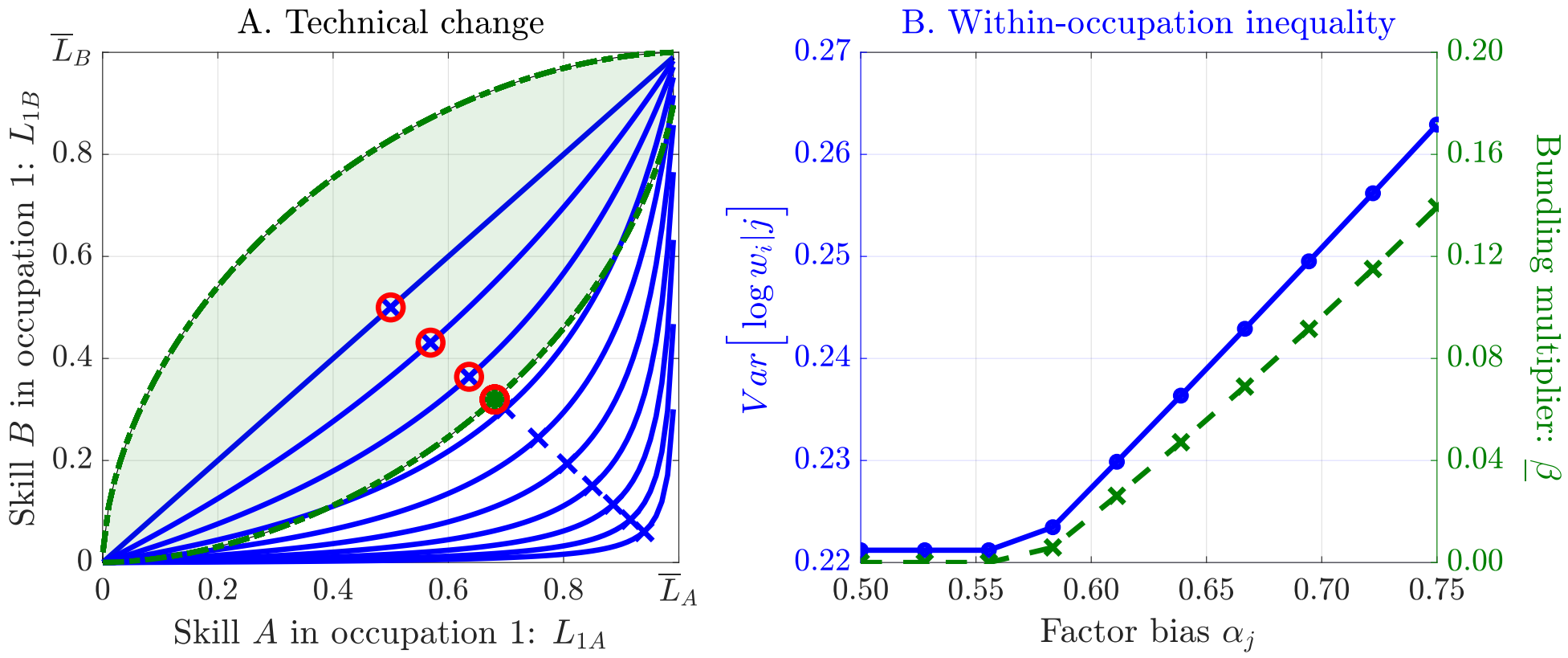
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Skill bias and inequality

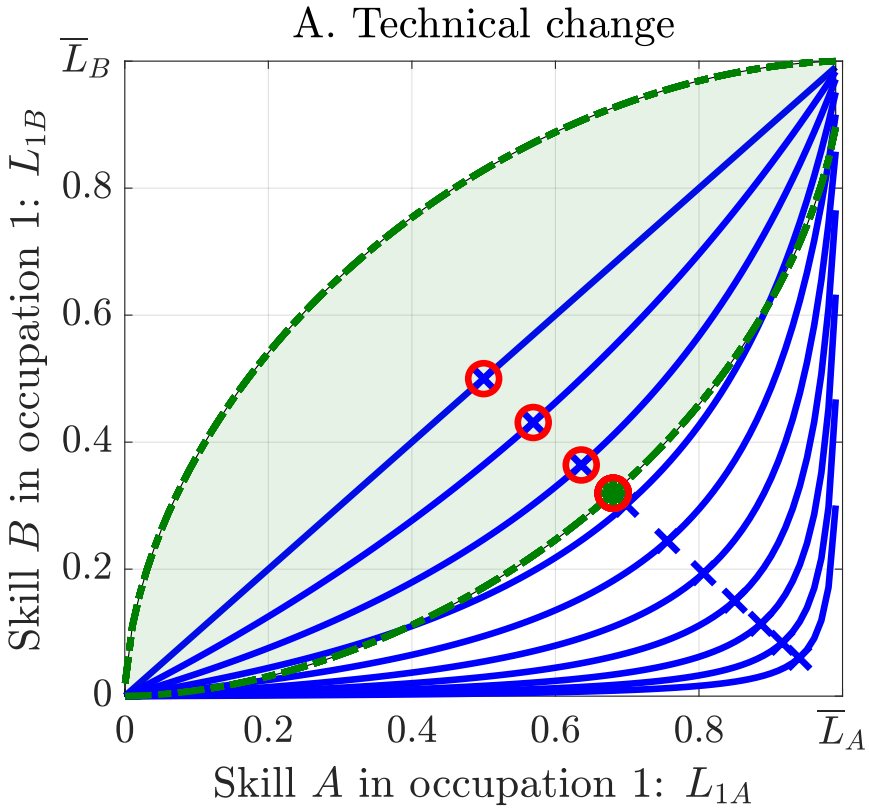
Varying $\alpha \in \{0.50, \ldots, 0.75\}$. As occupations become more different, bundling constraint binds and *primary* skill prices increase relative to *secondary* skill prices.

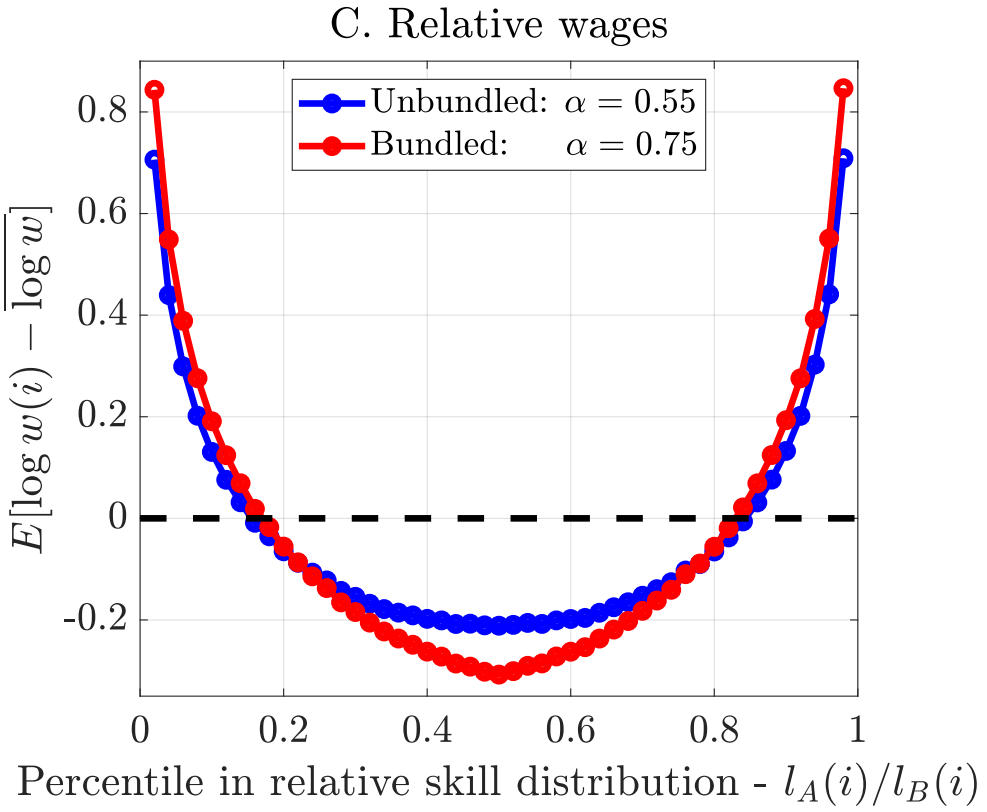


Other parameters: $\sigma = 0.60$, $\phi = 1$, $\theta = 2.25$, $\overline{L}_A = \overline{L}_B = 1$.

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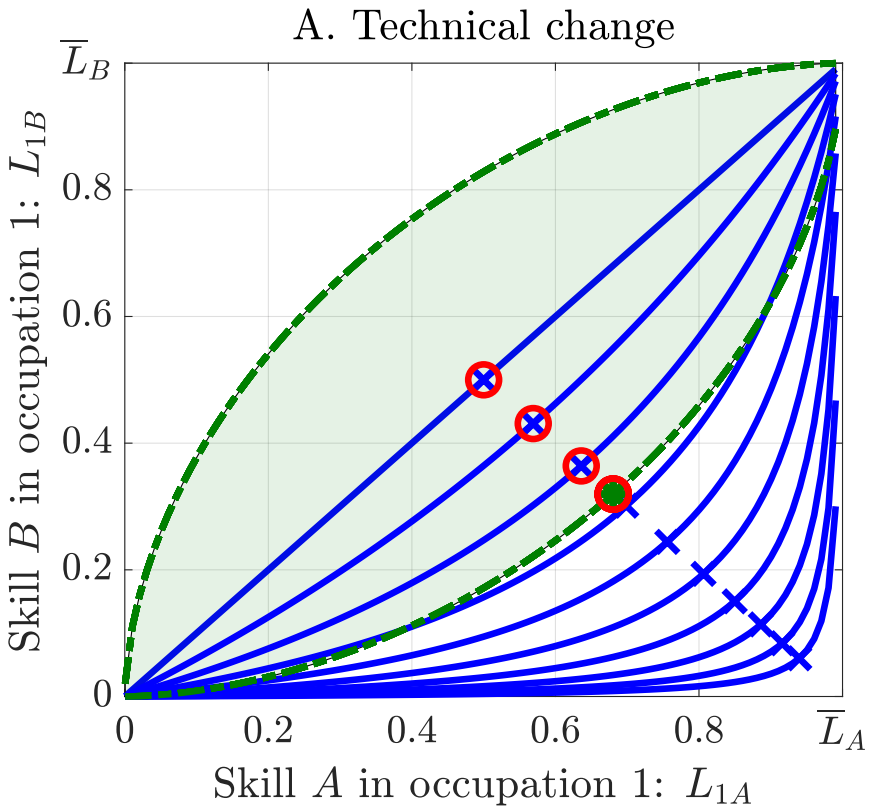


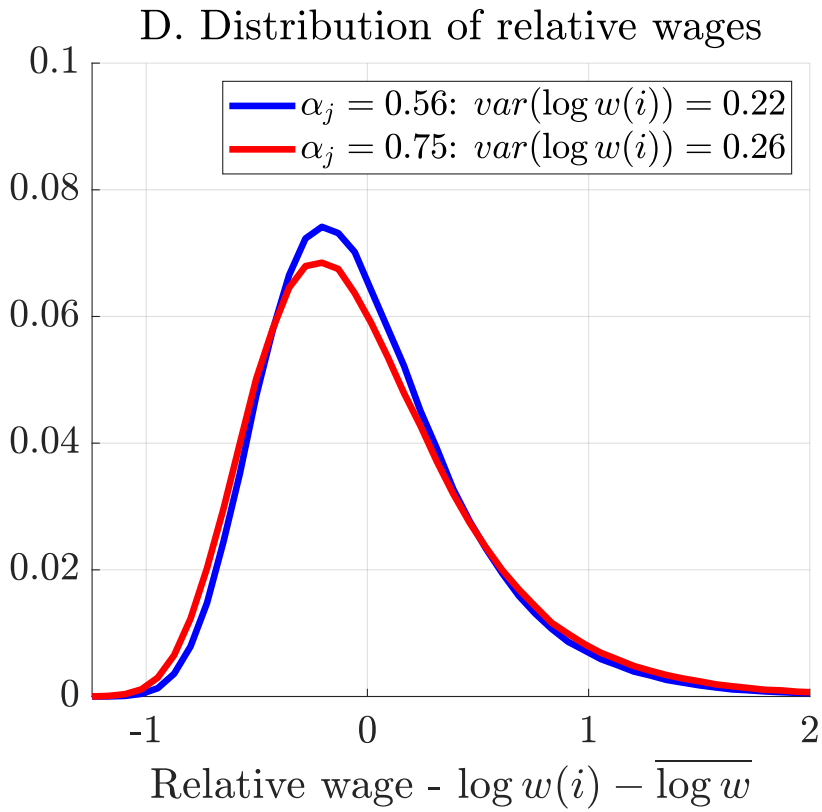


Wage: $w(i) = \omega_{1A} l_A(i) + \omega_{1B} l_B(i)$

Skill bias and inequality

Varying $\alpha \in \{0.50, \ldots, 0.75\}$. As occupations become more different, bundling constraint binds and *primary* skill prices increase relative to *secondary* skill prices.





Wage: $w(i) = \omega_{1A} l_A(i) + \omega_{1B} l_B(i)$

Low skill occupations in the US: 1970 vs 2020









Low skill occupations in the US: 1970 vs 2020

$\Uparrow$ *Skill bias* $\rightarrow$ *Bundled / Sorted equilibrium* $\rightarrow$ $\Uparrow$ *Inequality*





$\Downarrow$ *Skill bias* $\rightarrow$ *Unbundled / Unsorted equilibrium* $\rightarrow$ $\Downarrow$ *Inequality*





Low skill occupations in the US: 1970 vs 2020

$\Uparrow$ *Skill bias* $\rightarrow$ *Bundled / Sorted equilibrium* $\rightarrow$ $\Uparrow$ *Inequality*





$\Downarrow$ *Skill bias* $\rightarrow$ *Unbundled / Unsorted equilibrium* $\rightarrow$ $\Downarrow$ *Inequality*





In the paper - *Provide conditions under which these changes in factor intensities emerge endogenously from an expansion in the set of available technologies.*

This paper

1. Data

A. Skill requirement heterogeneity across occupations

$\downarrow$ Low skill jobs , $\uparrow$ High skill jobs

B. Wage inequality within occupations

$\downarrow$ Low skill jobs , $\uparrow$ High skill jobs

2. Theory

- Technological change consistent with **A.** causes **B.**
- Extend Rosen (1983), Heckman Scheinkman (1987)
- Endogenize **A.** as appropriate technology choice (Caselli Coleman, 2006)
- Add participation decision $(l_1, l_2) = (\psi, \psi x)$. Show efficiency properties.

3. Extension

- Declining *experience premium* in low skill jobs
- Declining *overtime premium / part-time penalty* in low skill jobs
- Increasing *occupation switching* in low skill jobs

Three special cases

$\underbrace{\textit{Katz-Murphy}}_{\theta \to 1}$, $\underbrace{\textit{Roy}}_{\alpha_j \to 1}$, $\underbrace{\textit{Lindenlaub}}_{J \to \infty}$

Three special cases

$$\underbrace{\textit{Katz-Murphy}}_{\theta \to 1}\ ,\ \underbrace{\textit{Roy}}_{\alpha_j \to 1}\ ,\ \underbrace{\textit{Lindenlaub}}_{J \to \infty}$$

1. Katz-Murphy

$$Y_j = \left[A_{jL} L_L^{\sigma} \ + \ A_{jH} L_H^{\sigma} \right]^{\frac{1}{\sigma}} \quad , \quad l(i) \in \left\{ \left(l_L(i), 0 \right) , \left(0, l_H(i) \right) \right\}$$

'Complete' skill supply $\Rightarrow$ Always unbundled

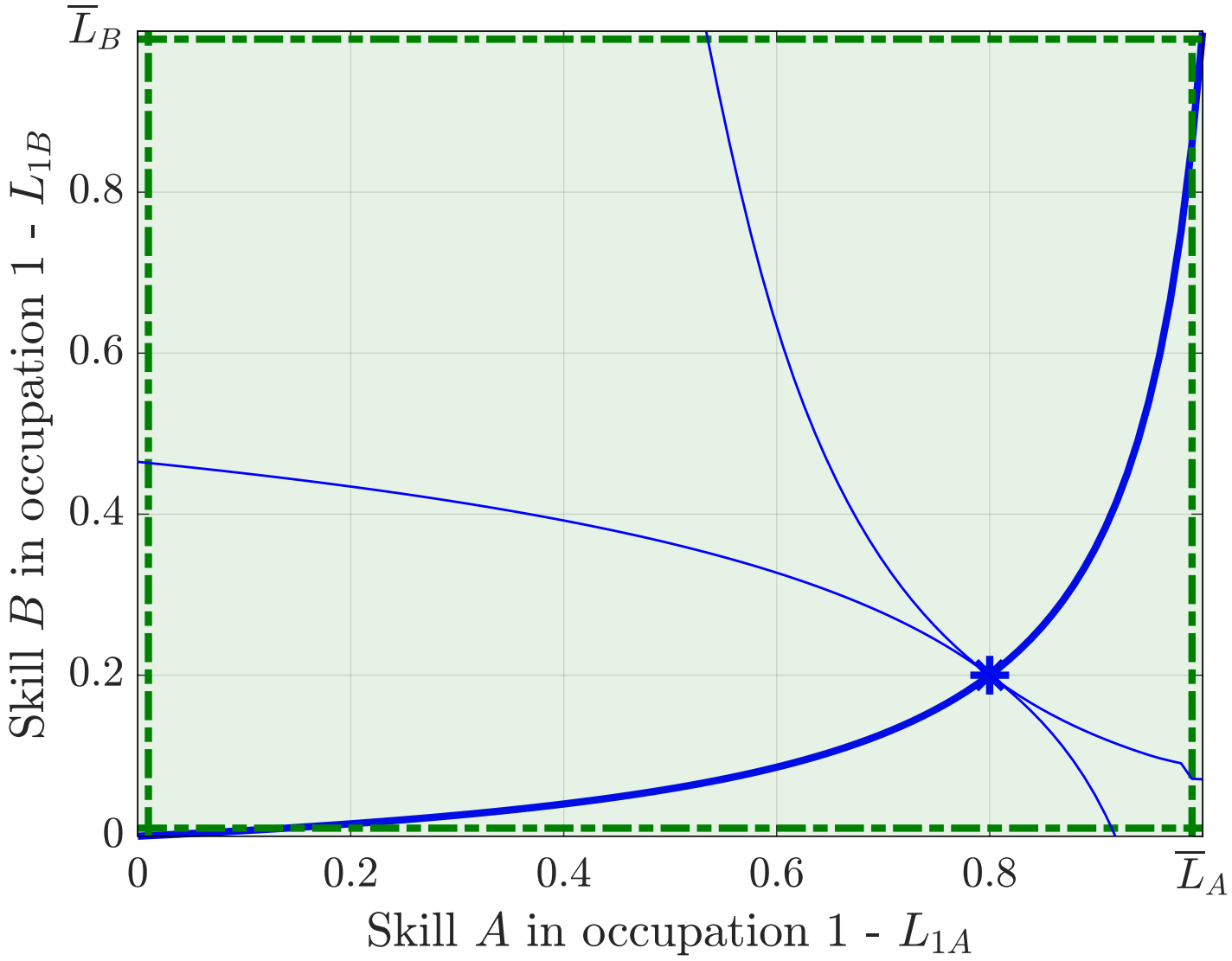
Law of one price holds for each skill

$$w(i) \ = \ \omega_A l_L(i) + \omega_B l_H(i)$$

$$var\left(\log w(i) \,\middle|\, j \right) \ = \ var\left(\log w(i) \right)$$

1. Katz-Murphy

Entire set feasible. Equilibrium always unbundled, regardless of technology. Workers not sorted. All workers indifferent. No rents due to comparative advantage. $w_j(i) = \omega_j l_j(i)$



Three special cases

$$\underbrace{\textit{Katz-Murphy}}_{\theta \to 1}\ ,\ \underbrace{\textit{Roy}}_{\alpha_j \to 1}\ ,\ \underbrace{\textit{Lindenlaub}}_{J \to \infty}$$

2. Generalized Roy model

$$Y_j = Z_j L_{jA} \quad , \quad L_{jA} = \int l_A(i)\phi_j(i)\, di \quad , \quad l_A(i) = F_j\Big(\boldsymbol{x}(i)\Big)$$

Extreme factor bias $\Rightarrow$ Always bundled

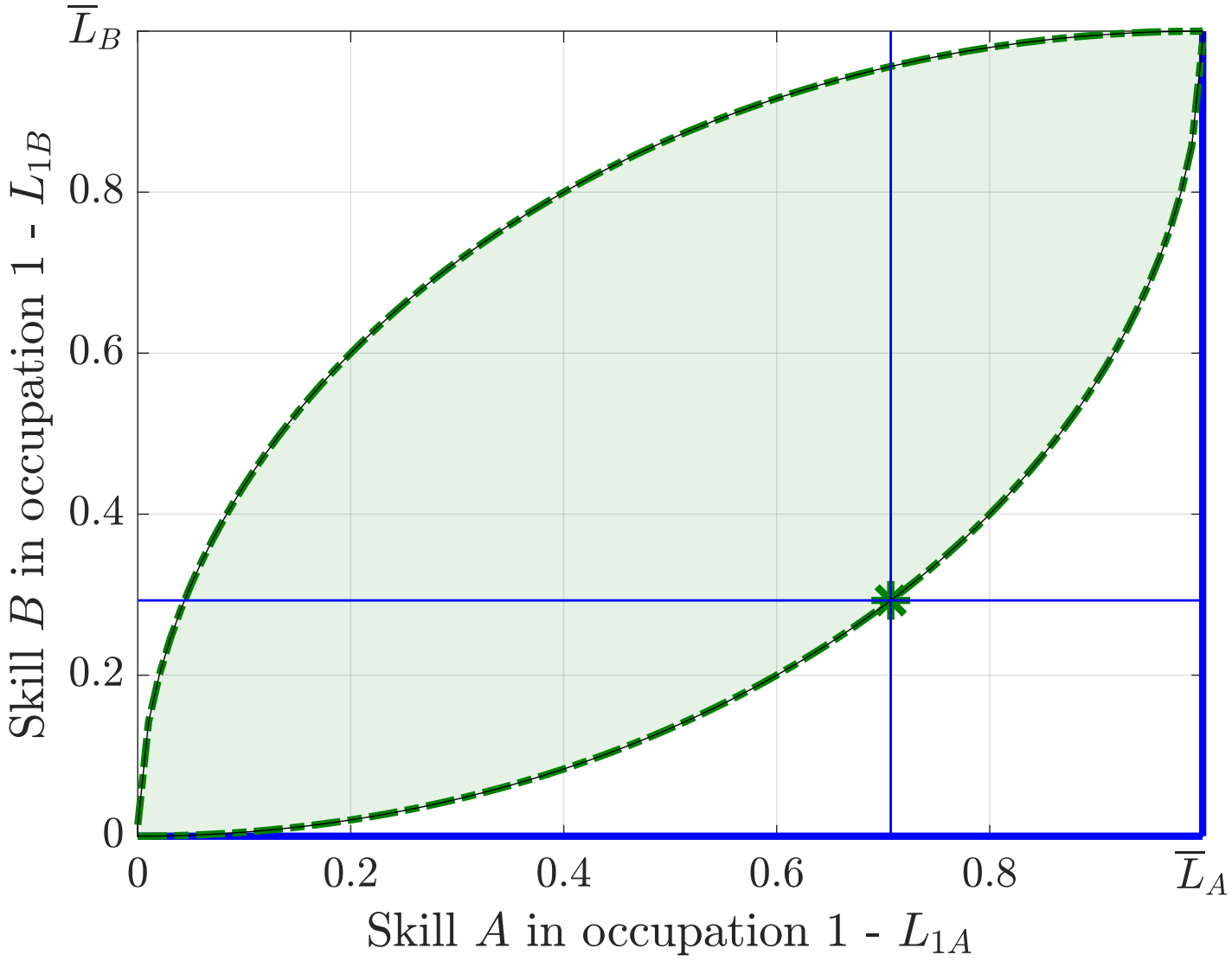
One positive price for each 'skill'

$$w_1(i) \;=\; \omega_{1A} l_A(i) + 0\, l_B(i)$$

$$var\Big(\log w(i)\,\Big|\, j\Big) \;=\; var\Big(\log l_A(i)\,\Big|\, i < i^*\Big)$$

2. Roy

Equilibrium always bundled. Workers sorted by comparative advantage. Skill prices ω_{1A}/ω_{2B} pinned down by relative skills of marginal worker, x^*. $w_j(i) = \omega_j l_j(i)$



Three special cases

$$\underbrace{\textit{Katz-Murphy}}_{\theta \to 1}\ ,\ \underbrace{\textit{Roy}}_{\alpha_j \to 1}\ ,\ \underbrace{\textit{Lindenlaub}}_{J \to \infty}$$

3. Lindenlaub

$$\int_0^m L_{jB} = \underline{B}\left(\int_0^m L_{jA}\right) \quad \text{for all } m \in [0, J] \quad \rightarrow \quad \underline{\beta}_m$$

1:1 matching $\Rightarrow$ All workers are marginal

Continuum of skill prices

$$\begin{aligned} w_j(i) &= \omega_{jA} l_A(i) + \omega_{jB} l_B(i) \\ var\left(\log w(i) \,\middle|\, j\right) &= 0 \\ \omega_{mA} &= \omega_{1A} - \int_0^m \underline{\beta}_j \times \left(\frac{l_B(i^*(j))}{l_A(i^*(j))}\right) dj \end{aligned}$$

Appendix

Endogenous technology

Under what conditions do these changes in factor intensities emerge endogenously from an expansion in the set of available technologies?

1. Production function

$$Y_j = \left[\alpha_j \left(a_{jA} L_{jA}\right)^{\sigma} + (1-\alpha_j)\left(a_{jB} L_{jB}\right)^{\sigma}\right]^{1/\sigma}, \qquad \sigma < 1$$

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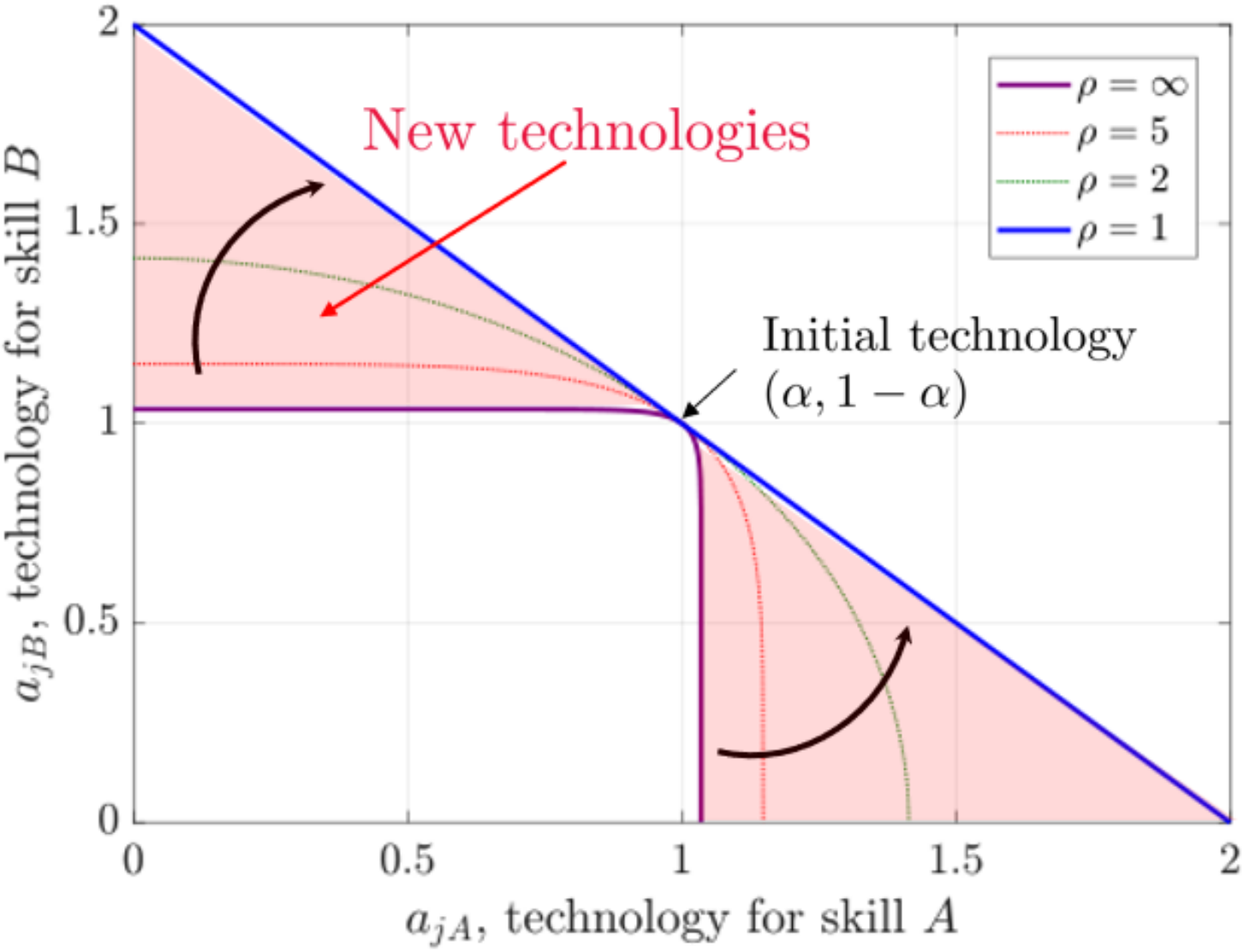
2. Minimize marginal cost subject to *available technologies*

$$\min_{a_{jA}, a_{jB}} \left[\left(\frac{\omega_{jA}}{\alpha_j^{1/\sigma} a_{jA}}\right)^{\frac{\sigma}{\sigma-1}} + \left(\frac{\omega_{jB}}{(1-\alpha_j)^{1/\sigma} a_{jB}}\right)^{\frac{\sigma}{\sigma-1}}\right]^{\frac{\sigma-1}{\sigma}}$$

$$\text{s.t.} \quad \left[a_{jA}^{\rho} + a_{jB}^{\rho}\right]^{1/\rho} = \overline{A}_j, \qquad \rho > 1$$

Available technologies

Technology frontier $\left[a_{jA}^{\rho} + a_{jB}^{\rho}\right]^{1/\rho} = \overline{A}_j$. As $\rho \searrow 1$ can reach more combinations of a_{jA}, a_{jB} for given $\overline{A}_j$.



Competitive equilibrium

- Skill prices determine technology adoption

$$\omega_{jk} \qquad \Longrightarrow \qquad a^*_{jk}$$

Caselli-Coleman (2006)

- Adopted technology determines sorting and skill premia

$$a^*_{jk} \qquad \Longrightarrow \qquad \underline{\beta} \geq 0 \qquad \Longrightarrow \qquad \omega_{jk}$$

Rosen (1983), Heckman Scheinkman (1987)

Example

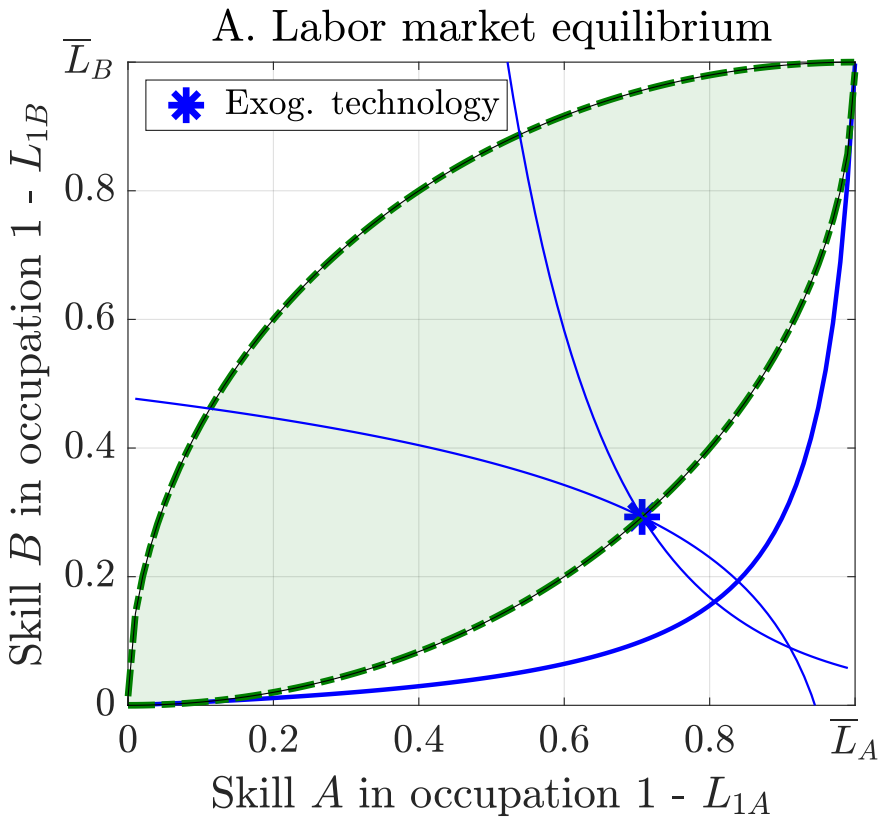
- Symmetric sectors
- Innate skill bias $\alpha_j = 0.8$
- Short-run $\rho = \infty \implies a_{jk} = 1$
- Long-run $\rho = 1$, choose technologies
- Production function CES with e.o.s. σ
- Result

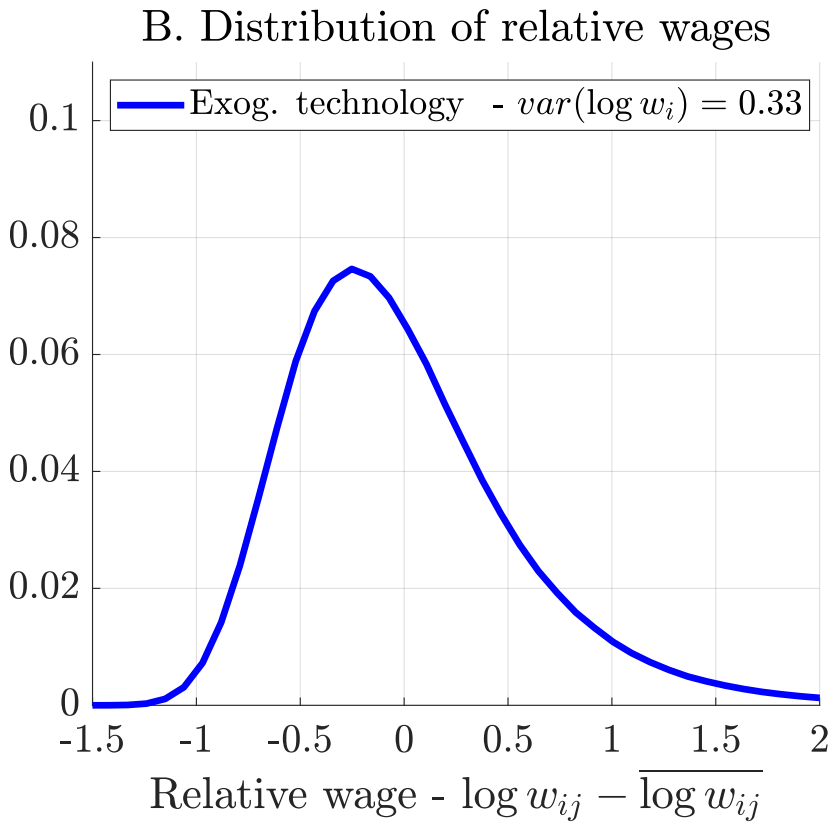
$\sigma > 0$ skills are substitutes $\rightarrow$ *bundling* $\sim$ High skill occupations

$\sigma < 0$ skills are complements $\rightarrow$ *unbundling* $\sim$ Low skill occupations

Bundling labor: $\sigma > 0$

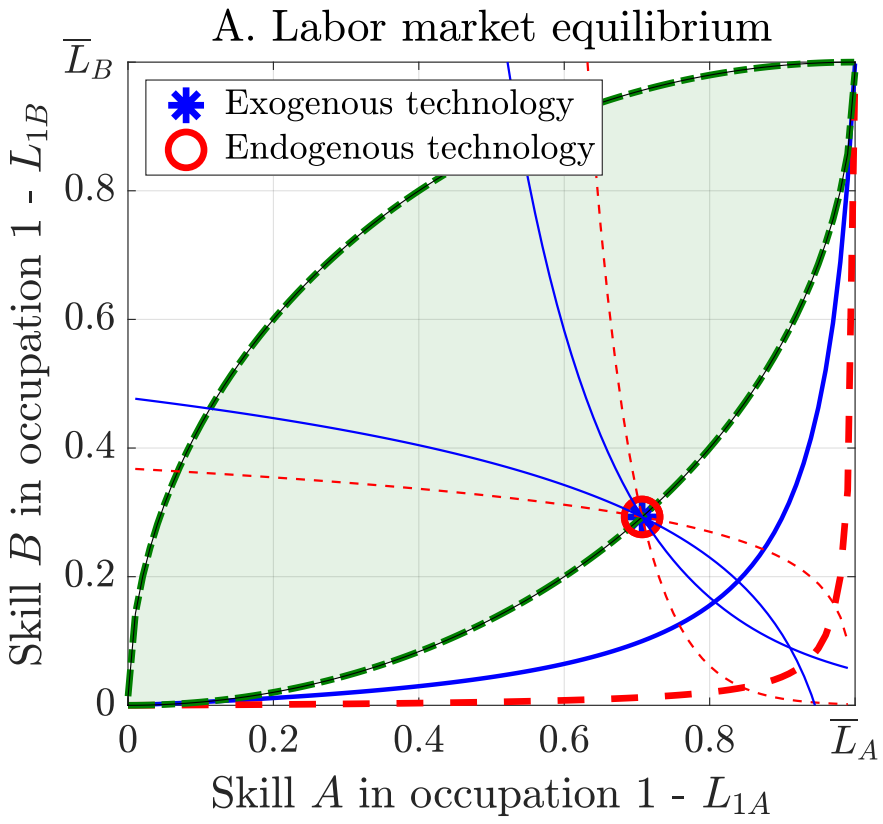
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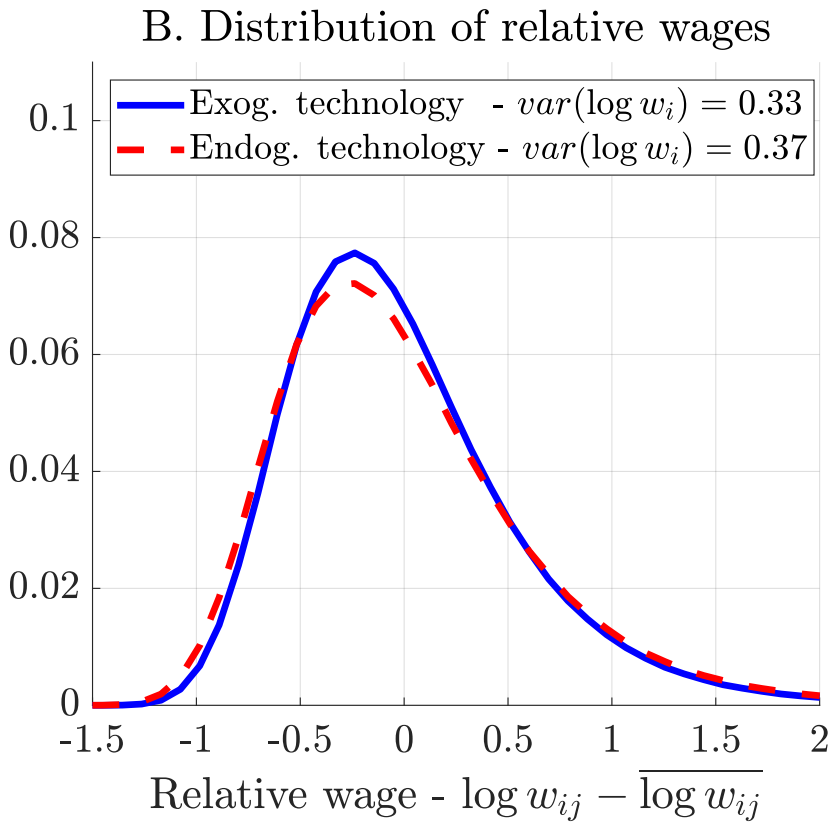




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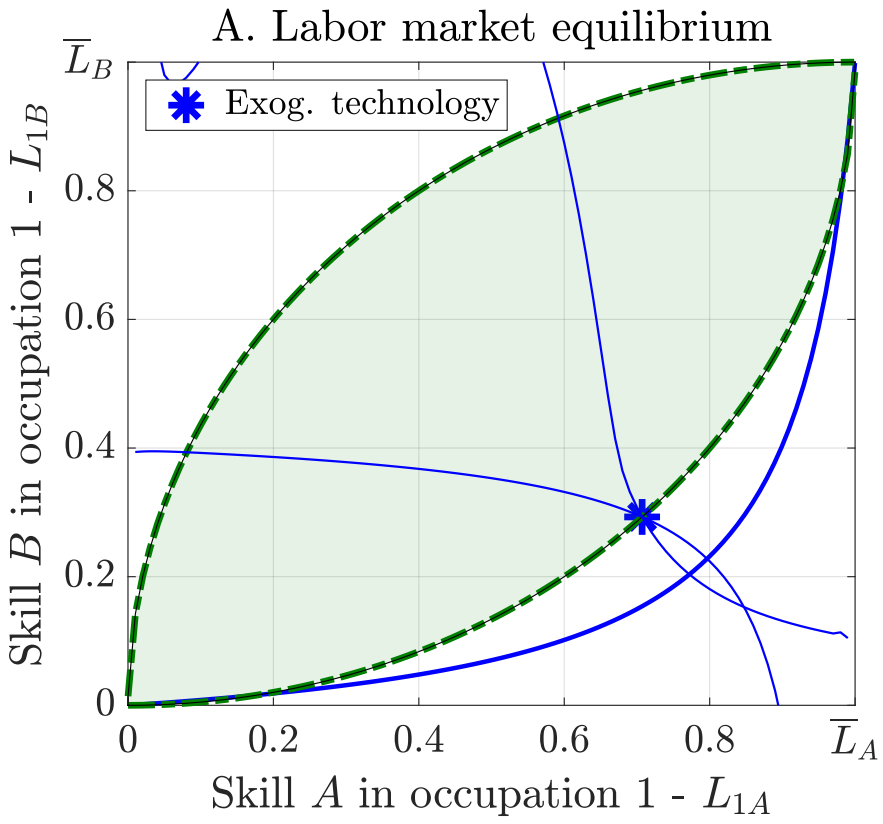
Skills are substitutes, $\sigma > 0$. Choose technology more skill biased. *Endogenously more 'Roy-like'. Bundling constraints tighter. Specialist wages increase. Increasing inequality.*

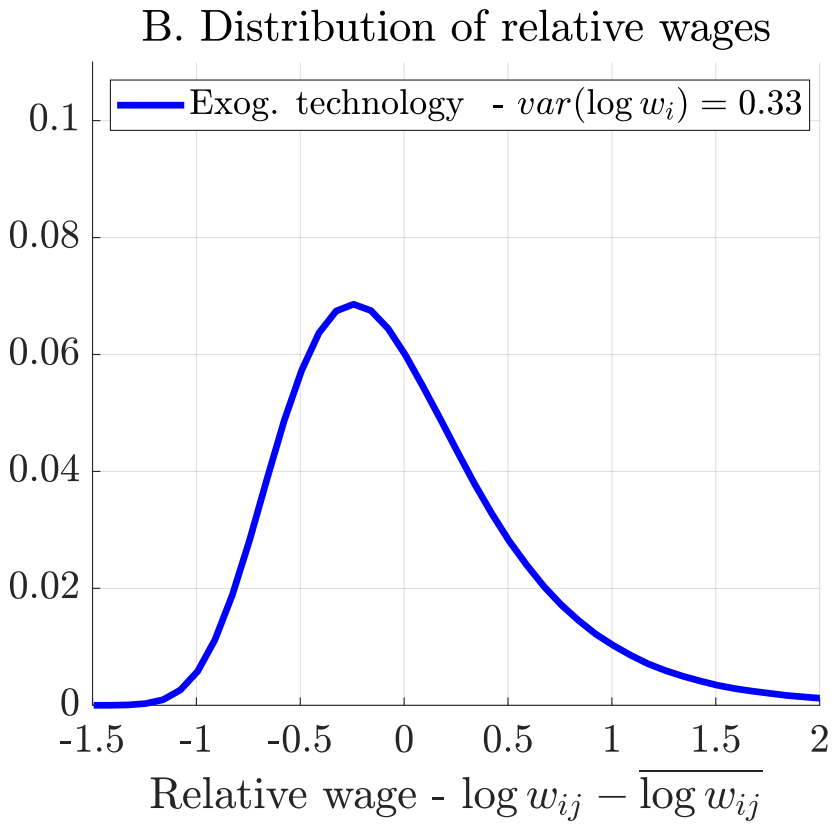




Unbundling labor: $\sigma < 0$

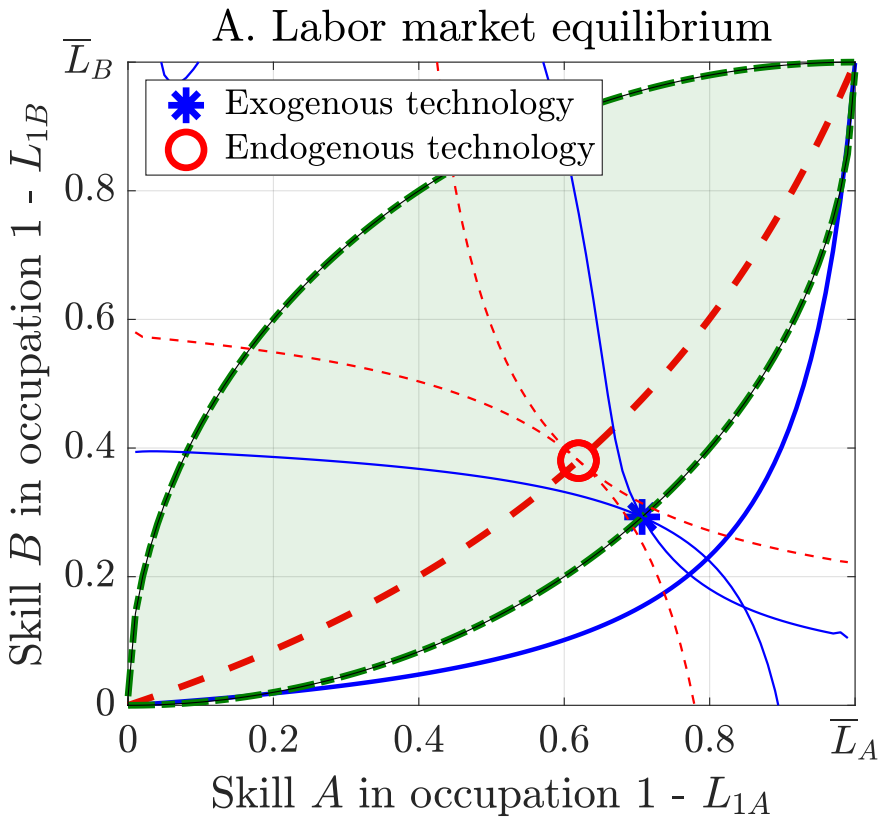
Skills are complements, $\sigma < 0$.

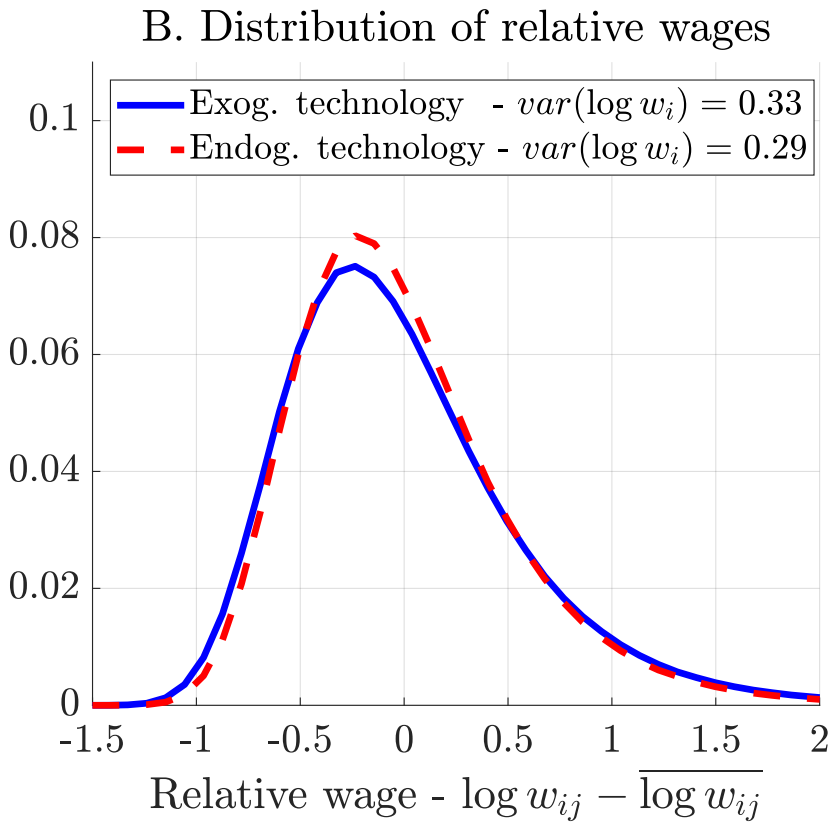




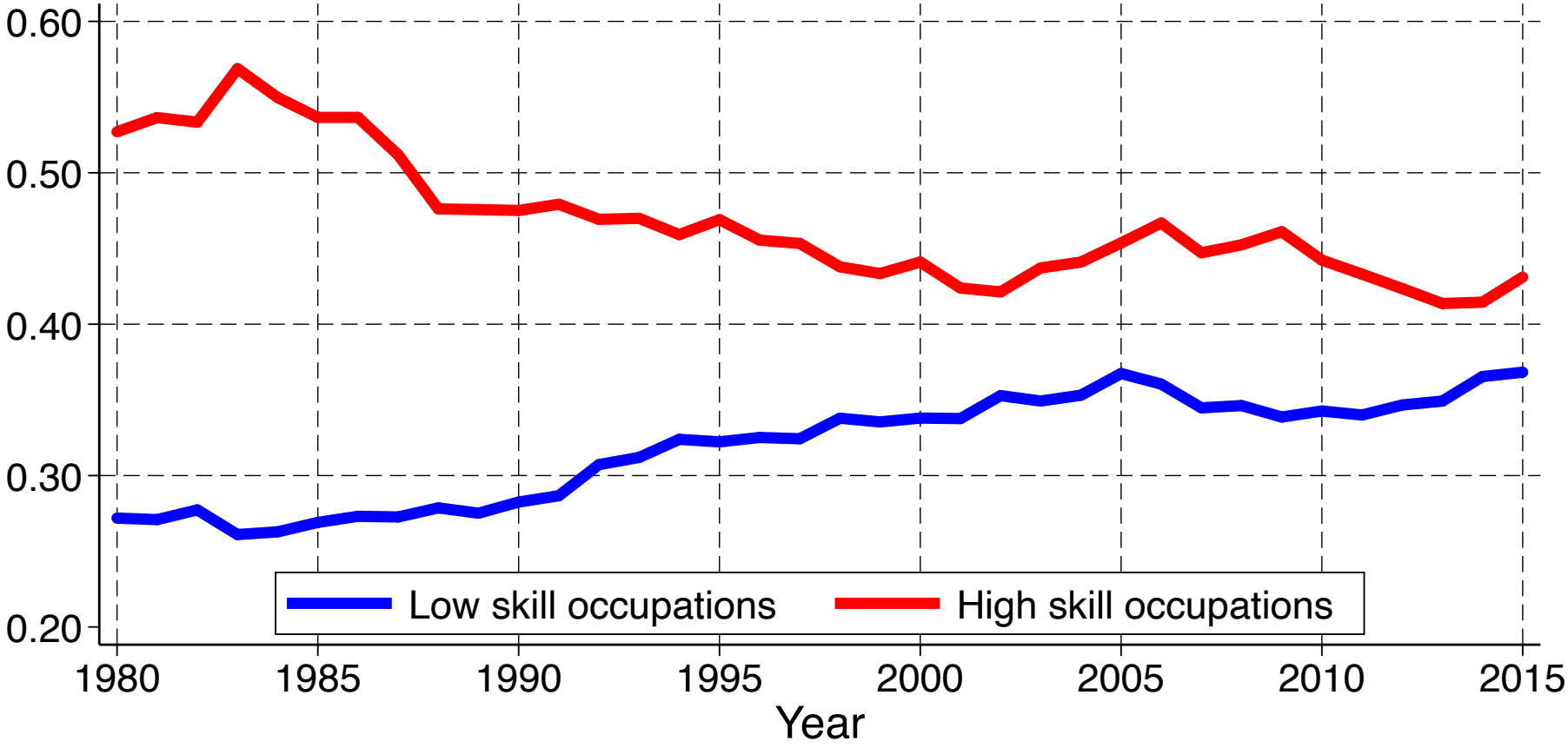
Unbundling labor: $\sigma < 0$

Skills are complements, $\sigma < 0$. Choose technology less skill biased. *Bundling constraints slack. Wage gains for generalists. Wage losses for specialists. Decreasing inequality.*





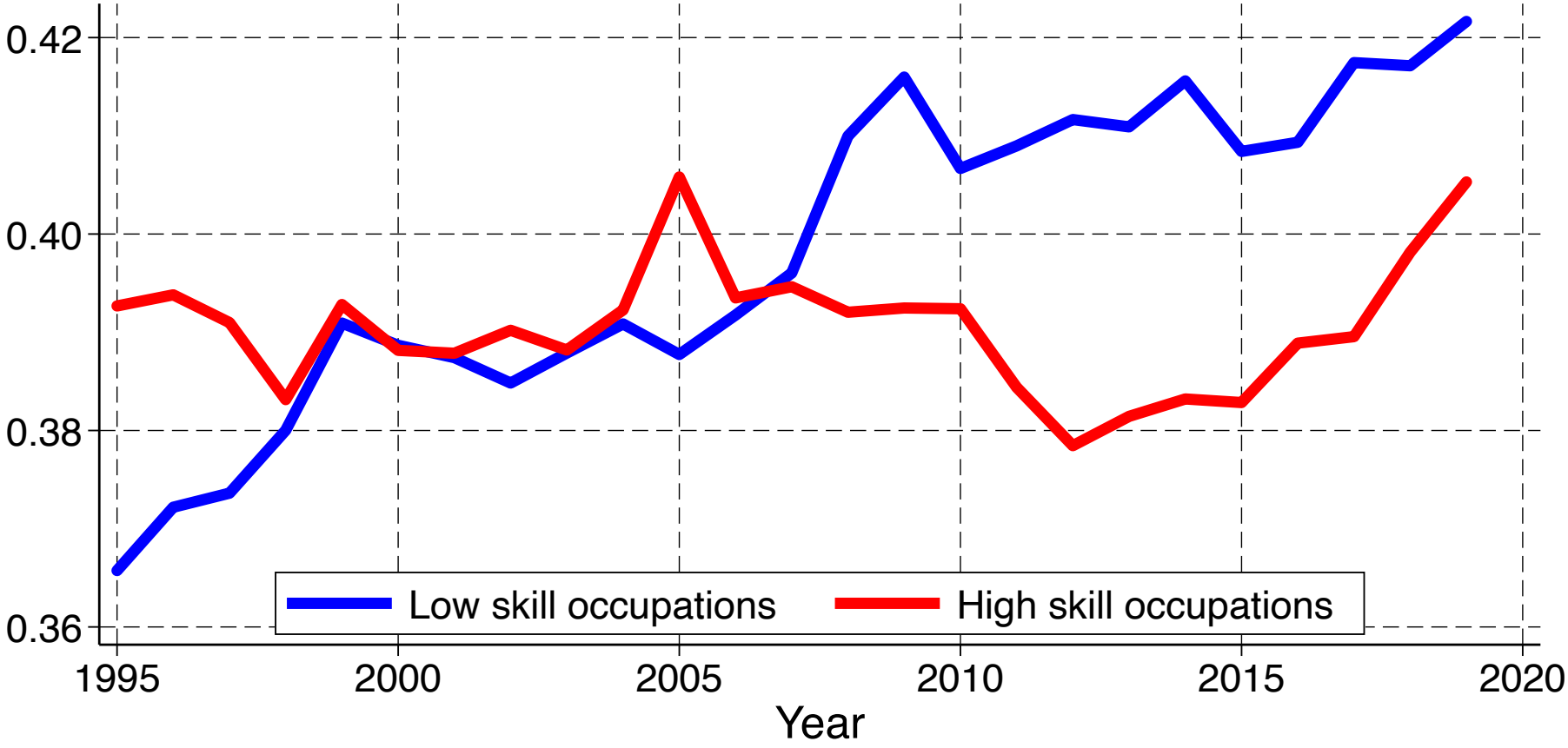
1. Occupation switching



Fraction of **male** workers experiencing $\left\{E_{March}, \ldots, U_m, \ldots, E_{March'}\right\}$

that swap **1-digit** occupations across $\left\{E_{March}, E_{March'}\right\}$

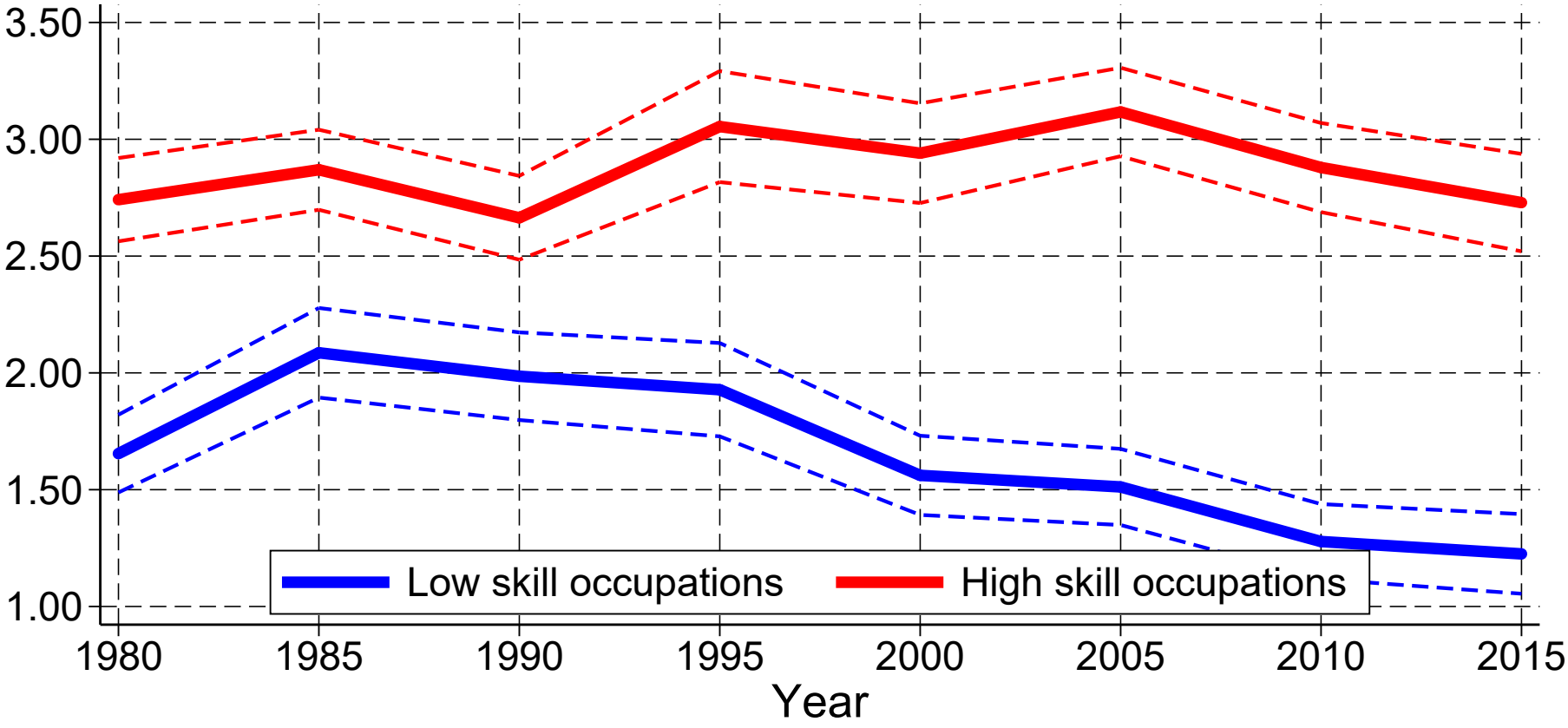
1. Occupation switching



Fraction of **male** workers experiencing $\left\{E_{Month}, E_{Month+1}\right\}$

that swap **1-digit** occupations across $\left\{E_{Month}, E_{Month+1}\right\}$

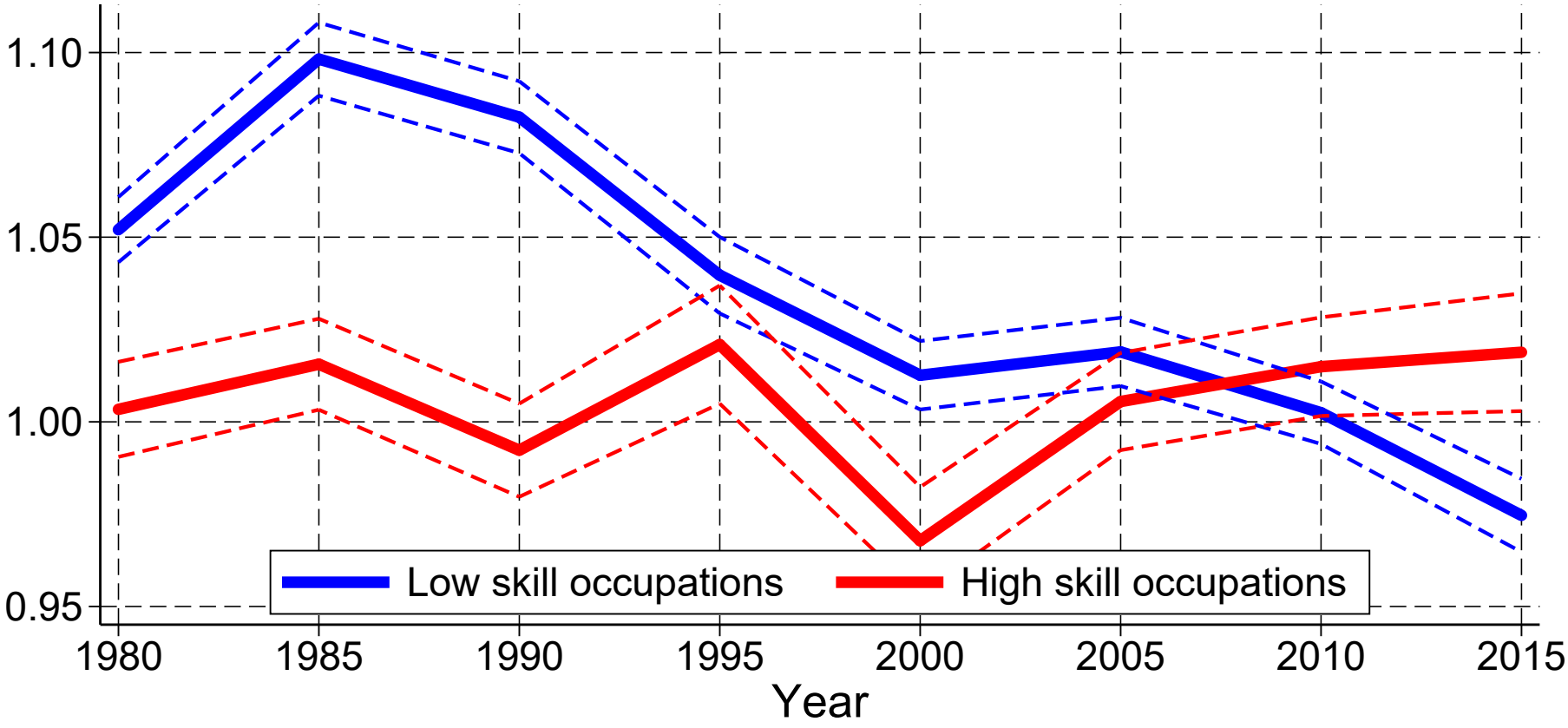
2. Experience premium



One extra year experience associated with 2 to 3 percent higher wage

$$\log Inc_{it} = \alpha + \beta^{\tau}_{Hours} \log Hours_{it} + \beta^{\tau}_{Exp} Exp_{it} + \beta^{\tau}_{Exp^2} Exp^2_{it} + \beta^{\tau}_{Size} Size_{it} \ldots$$
$$+\beta^{\tau}_{X} \left[Year_t, Race_{it}, NAICS1_{it}, Ed_{it}, Sex_{it}\right]$$

3. Hours premium



$(= 1)$: wage independent of hours, (≥ 1): wage increasing in hours

$$\log Inc_{it} = \alpha + \beta^{\tau}_{Hours} \log Hours_{it} + \beta^{\tau}_{Exp} Exp_{it} + \beta^{\tau}_{Exp^2} Exp^2_{it} + \beta^{\tau}_{Size} Size_{it} \ldots + \beta^{\tau}_{X} \left[Year_t, Race_{it}, NAICS1_{it}, Ed_{it}, Sex_{it}\right]$$

Interpreting other facts

1. Increasing *occupation switching* in low skill occupations

2. Declining *experience premium* in low skill occupations

3. Declining *overtime premium / part-time penalty* in low skill occupations

Interpreting other facts

1. Increasing *occupation switching* in low skill occupations
    - Unbundled equilibrium features indeterminate occupational choice
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1. Increasing *occupation switching* in low skill occupations
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2. Declining *experience premium* in low skill occupations
   - Add learning by doing in the direction of occupation skill bias
     Cavounidis Lang (JPE, 2020)
   - Experience premium $\leftrightarrow$ Inframarginal rents
   - Unbundling labor reduces gradient of primary / secondary skill prices
   - Reduces observed experience premium
3. Declining *overtime premium / part-time penalty* in low skill occupations

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   - Reduces observed experience premium
3. Declining *overtime premium / part-time penalty* in low skill occupations
   - Requires more work to extend the model
   - Unbundling labor $\leftrightarrow$ Workers are more 'substitutable'

Conclusions

- Deviations from law of one price for skills if either
  - **(i)** technologies sufficiently factor biased, or
  - **(ii)** weak pattern of comparative advantage in skills

- Can generate opposite trends in *within-occupation wage inequality* from technology adoption consistent with the data

- If skills *substitutes*, technology adoption *tightens bundling constraints*
  - ↑ returns to comparative advantage, ↑ sorting
  - ↑ within-occupation wage inequality
  - Consistent with experience of *high skill occupations*

- If skills *complements*, technology adoption *can cause unbundling*
  - ↓ returns to comparative advantage, ↓ sorting
  - ↓ within-occupation wage inequality
  - Consistent with experience of *low skill occupations*

Comparative statics

1. *Symmetric change in factor bias* - $\boldsymbol{\alpha}$
2. *Task-biased change* - Z_1
3. *Skill-biased change* - ψ_A
4. *Task-skill-biased change* - ζ_{1A}

$$U\left(Y_1, Y_2\right) = \left[\eta Y_1^{\frac{\phi-1}{\phi}} + (1-\eta) Y_2^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}} \qquad \phi > 1$$

$$Y_1 = Z_1 \left[\zeta_{1A}\, \psi_A\, \alpha L_{1A}^{\sigma} + (1-\alpha) L_{1B}^{\sigma}\right]^{\frac{1}{\sigma}}$$

$$Y_2 = \left[\psi_A\, (1-\alpha) L_{2A}^{\sigma} + \alpha L_{2B}^{\sigma}\right]^{\frac{1}{\sigma}}$$

Within-occupation skill prices and inequality

1. Wages

$$w_1(i) = \omega_{1A}\, l_A(i) + \omega_{1B}\, l_B(i)$$

2. Sorting
   - Occupation 1 chosen by individuals with high $\Uparrow l_A(i)/l_B(i)$

3. Inequality
   - Increases as gradient of skill prices steepens $\Uparrow \omega_{1A}/\omega_{1B}$
   - Decreases as gradient of skill prices flattens $\Downarrow \omega_{1A}/\omega_{1B}$

In the paper

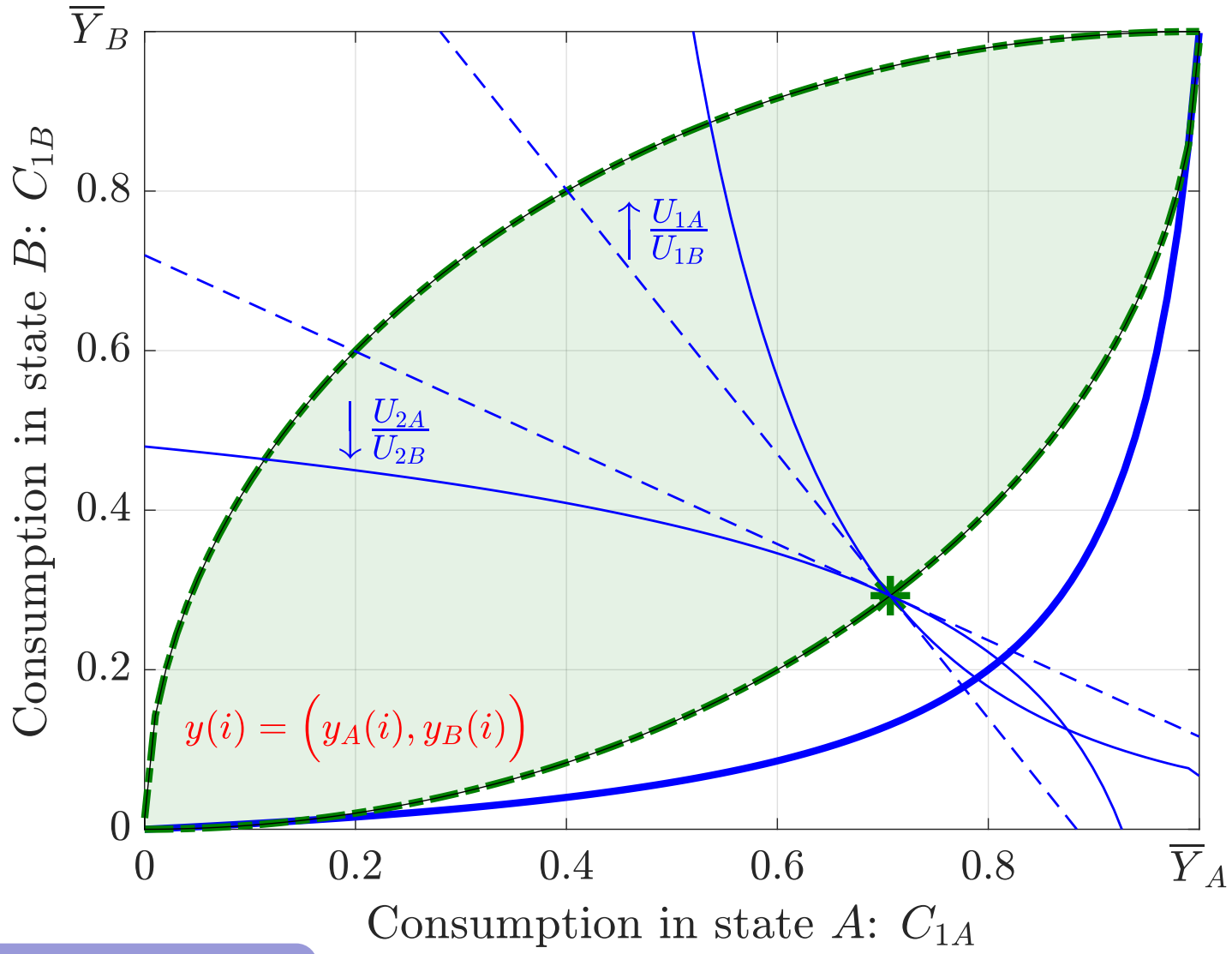
- Closed form example under $\left(l_A(i), l_B(i)\right) = \left(e^{\alpha(1-i)}, e^{\alpha i}\right)$
- Log-linear approximation to compute conditional variance
- Decomposes $var\left(\log w(i)|j\right)$ into (i) Endowments, (ii) Prices

▸ Results - Closed form example

Incomplete markets allocation

Bundling constraint binds. Cannot 'break open' assets to get at underlying arrow securities

$$U_{1A} + \underline{C}'(C_{1A})U_{1B} = U_{2A} + \underline{C}'(C_{1A})U_{2B}$$



Back - Bundled allocation

Link to Bais, Hombert, Weill (2020)

- Setup - Two agents $j \in \{1,2\}$ consume in two states $k \in \{A,B\}$
- Preferences - Expected utility of consumption

$$F_j\left(C_{jA}, C_{jB}\right) = \pi_A \alpha_j \frac{C_{jA}^{1-\gamma}}{1-\gamma} + \pi_B \left(1-\alpha_j\right) \frac{C_{jB}^{1-\gamma}}{1-\gamma} \quad , \quad \alpha_1 > \frac{1}{2} > \alpha_2$$

- Trees - Physical assets indexed $i \in [0,1]$ have payoffs

$$d(i) = \left(d_A(i), d_B(i)\right) \quad , \quad d_A(i)/d_B(i) \text{ decreasing in } i$$

- Budget constraints - Period-0 and Period 1, State-k

$$\int Q(i)\phi_j(i)\, di + q_A a_{jA} + q_B a_{jB} \quad \leq \quad \phi_j^0 \int Q(i)\, di$$

$$C_{jk} \quad = \quad \int \phi_j(i) d_k(i)\, di + a_{jk}$$

- Incentive compatibility - Only short arrow securities up to $(1-\delta)$ of tree payoffs

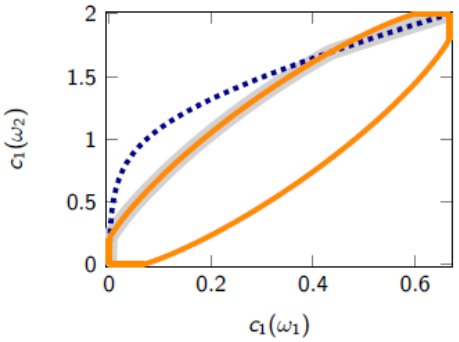
$$C_{jk} \geq \delta \int \phi_j(i) d_k(i)\, di \quad , \quad k \in \{A,B\}$$ Slack if $\delta = 0$. No shorts if $\delta = 1$

- Feasibility - What IC (C_{1A}, C_{2A}) can be supported by a set of trees?

$$C_{1A} = \delta \int_0^{k^*} d_A(i)\, di \rightarrow k^*(C_{1A}) \rightarrow \underline{C}_{1B}\left(C_{1A}\right) \geq \delta \int_0^{k^*(C_{1A})} d_B(i)\, di$$

Link to Bais, Hombert, Weill (2020)

the model in an edgeworth box



a graphical analysis of the incentive feasible set (IF set)

- area inside the orange curve: IF set with many trees and $\delta < 1$
- dotted-blue curve: Pareto set without IC constraints
- highlighted-grey curve: Pareto set with IC constraints

- Here w/out IC, trees redundant. Trade in Arrow securities. $Q(i) = \sum_k q_k d_k(i)$.
- If IC binds, ratios of marginal utilities not equated: $\omega_{1A}/\omega_{1B} > \omega_{2A}/\omega_{2B}$
- The price of tree i depends on which agent j holds it

$$Q_1(i) = q_A d_A(i) + (q_B - \delta\mu_{1B})\, d_B(i)\ ,\ Q_2(i) = (q_A - \delta\mu_{1A})\, d_A(i) + q_B d_B(i)$$

- In equilibrium $\omega_{1A} > \omega_{2A}$ and $\omega_{1B} < \omega_{2B}$, which implies $\omega_{1A} > \omega_{1B}$
- Result - Securities with more extreme pay-offs (specialists) are more expensive
- Result - Price of tree encodes constraint, lower than replicating arrow securities

Competitive equilibrium

$$\Pi_1 = \max_{L_{1A}, L_{1B}} P_1 F_1\left(L_{1A}, L_{1B}\right) - Cost_1\left(L_{1A}, L_{1B}\right)$$

$$Cost_1\left(L_{1A}, L_{1B}\right) = \min_{\widetilde{\phi}_1(i)} \int \widetilde{\phi}_1(i) w_1(l_A, l_B)\, di$$

subject to

$$L_{1A} = \int \widetilde{\phi}_1(i)\, l_A\, di \longrightarrow \omega_{1A} = P_1 F_{1A} \quad \left(MC_{1A} = MRPL_{1A}\right)$$

$$L_{1B} = \int \widetilde{\phi}_1(i)\, l_B\, di \longrightarrow \omega_{1B} = P_1 F_{1B} \quad \left(MC_{1B} = MRPL_{1B}\right)$$

Labor demand for each type

$$\widetilde{\phi}_1(i) = \begin{cases} 1 & , \quad \text{if} \quad \omega_{1A} l_A(i) + \omega_{1B} l_B(i) > w_1\left(l_A, l_B\right) \\ 0 & , \quad \text{if} \quad \omega_{1A} l_A(i) + \omega_{1B} l_B(i) < w_1\left(l_A, l_B\right) \\ \in (0,1) & , \quad \text{if} \quad \omega_{1A} l_A(i) + \omega_{1B} l_B(i) = w_1\left(l_A, l_B\right) \end{cases}$$

Back - Two allocations

Competitive equilibrium

- Prices per efficiency unit of skill

$$\begin{aligned} w_j\left(l_A, l_B\right) &= \omega_{jA} l_A + \omega_{jB} l_B \\ \omega_{jk} &= P_j F_{jk} = U_j F_{jk} \end{aligned}$$

- Worker (l_A, l_B) chooses occupation $j = 1$ only if

$$w_1\left(l_A, l_B\right) > w_2\left(l_A, l_B\right)$$

- Cutoff worker indifferent

$$\underbrace{\frac{\omega_{1A} - \omega_{2A}}{\omega_{2B} - \omega_{1B}}}_{\text{Benefit of } j=1} = \underbrace{\left(\frac{l_B}{l_A}\right)^*}_{\text{Relative skill in } j=2} = \underline{B'}\left(L_{1A}\right)$$

Under $\{\omega_{jk} = U_j F_{jk}\}$, this is the same condition as in the planner's problem

Back - Two allocations

Competitive equilibrium

- *Bundled equilibrium*: Sorting premia are increasing in $\underline{\beta}$

$$\omega_{1A} - \omega_{2A} = \underline{\beta}\, \underline{B}'(L_{1A})$$
$$\omega_{2B} - \omega_{1B} = \underline{\beta}$$

– Inframarginal workers earn rents due to comparative advantage, determined by sorting premia.

– Additional source of within-occupation wage inequality

- *Unbundled equilibrium*: Sorting premia are zero, indeterminate sorting

$$\omega_{1A} - \omega_{2A} = 0$$
$$\omega_{2B} - \omega_{1B} = 0$$

– All workers are marginal. No rents due to comparative advantage.

Back - Two allocations

Generalized Roy model

- Individual-occupation specific output

$$y_j(i) = \exp\left(\alpha_{jA} l_A(i) + \alpha_{jB} l_B(i)\right) \quad , \quad Y_j = \int \phi_j(i) y_j(i)\, di$$

- The *only* priced objects are $y_1(i)$, $y_2(i)$ with prices w_1, w_2

$$\log w_j(i) = \log w_j + \alpha_{jA} l_A(i) + \alpha_{jB} l_B(i)$$

- In our case

$$\log w_j(i) \approx \log \overline{w}_j + \widetilde{\omega}_{jA} \widehat{l}_A(i) + \widetilde{\omega}_{jB} \widehat{l}_B(i)$$

1. Technology affects wages directly through the technology coefficients
2. Within occupation inequality effects are silo-ed:
   - Suppose that technology changes in occupation 2
   - All changes in the economy are encoded in the *occupation skill price* w_j, i.e. the occupation fixed effect
   - No change in incumbent *within occupation inequality* in occupation 1

Back - When is the equilibrium bundled?

Wage inequality - Closed form example

- Skills for individuals $i \in [0,1]$

$$\Big(l_A(i), l_B(i)\Big) = \Big(\gamma e^{\alpha(1-i)}, \gamma e^{\alpha i}\Big) \quad \rightarrow \quad l_B(i)/l_A(i) = e^{\alpha(2i-1)}$$

- Approximate log wage around mean log skills conditional on selection i^*

$$\log w(i,j) = \log\left[\omega_{1A} e^{\log l_A(i)} + \omega_{1B} e^{\log l_B(i)}\right]$$

- Within occupation inequality

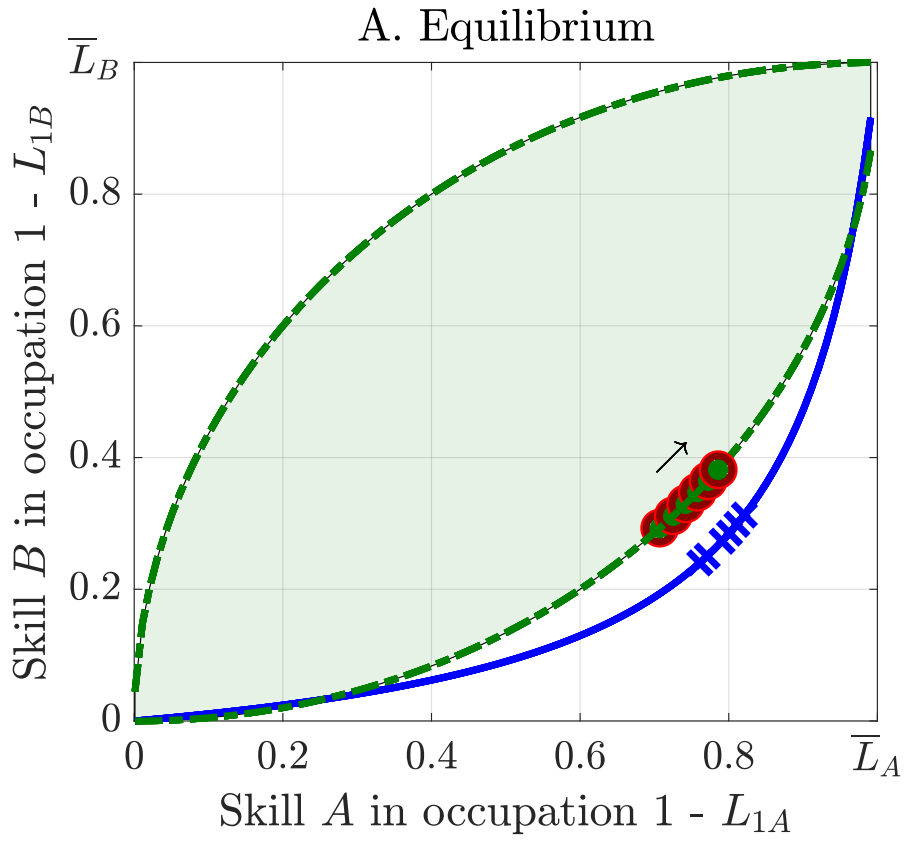
$$var\Big(\log(w(i)) \,\Big|\, j^*(i) = 1\Big) = \underbrace{\left(\frac{\left(\frac{\omega_{1A}}{\omega_{1B}}\right) e^{\alpha(1-i^*)} - 1}{\left(\frac{\omega_{1A}}{\omega_{1B}}\right) e^{\alpha(1-i^*)} + 1}\right)}_{\text{Bundling}} \underbrace{\alpha^2 \frac{i^{*\,2}}{12}}_{\text{Roy}}$$

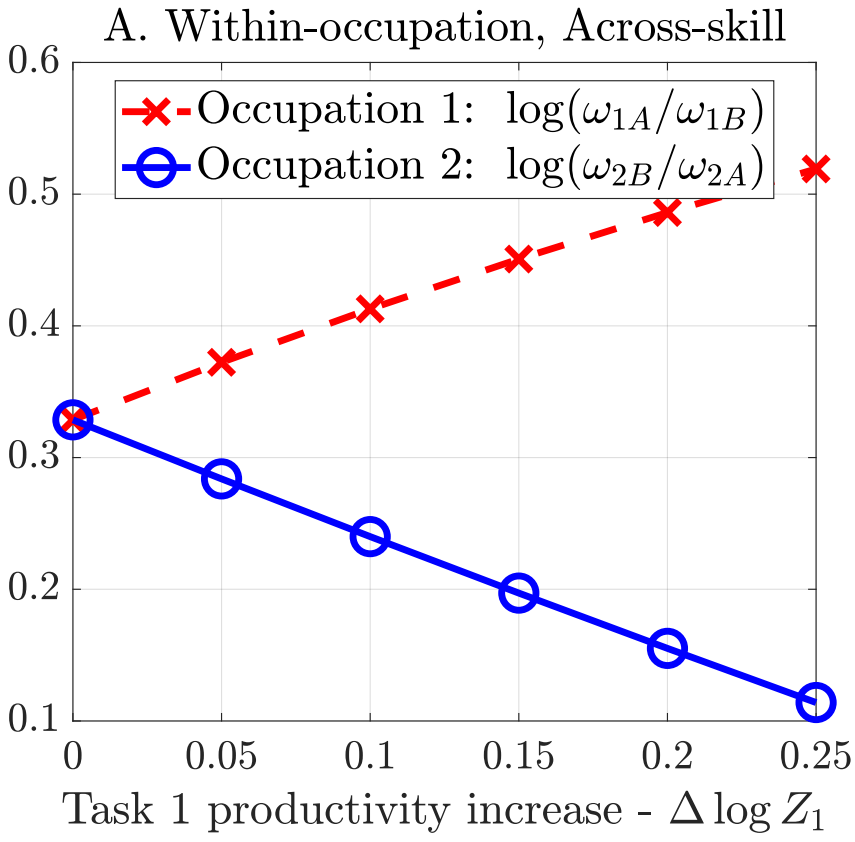
1. Roy — As $\omega_{1A}/\omega_{1B} \rightarrow \infty$, bundling terms goes to zero
2. Bundling — With finite ω_{1A}/ω_{1B}, inequality increasing in ratio

Back - Wage inequality

2. Task-Biased Change

Exogenous $\uparrow Z_1$, with $\phi > 1$: $\uparrow Y_1$, $\downarrow Y_2$.
Marginal worker has more Skill B, pushes up ω_{1A}/ω_{1B}. Opposite for task 2.



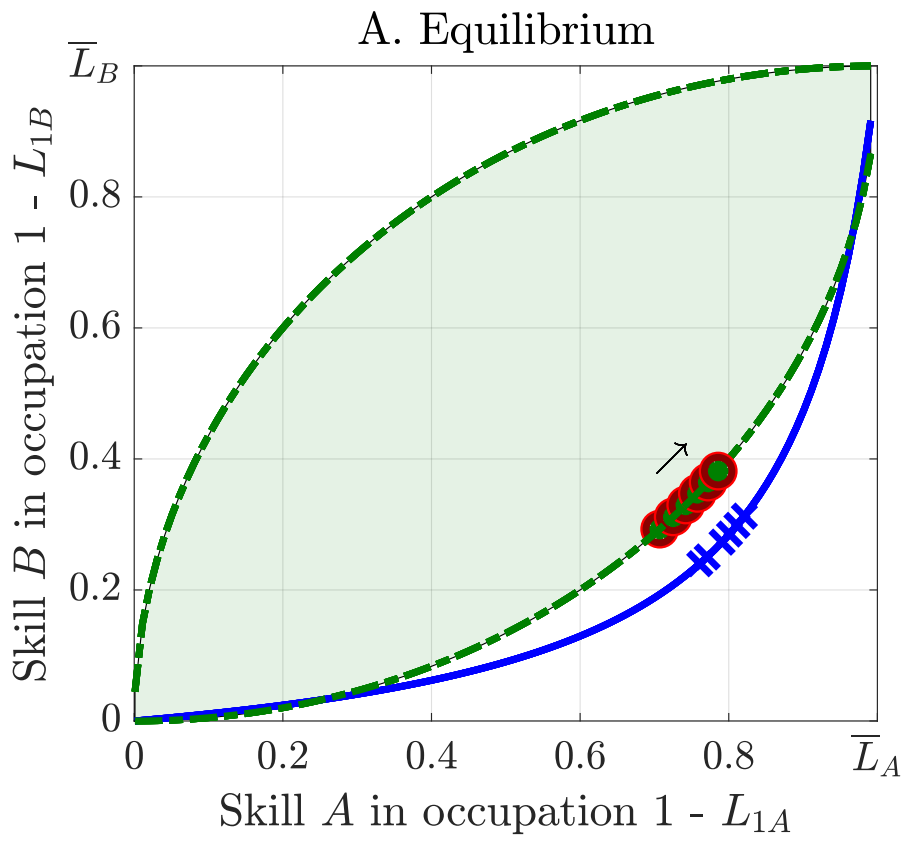


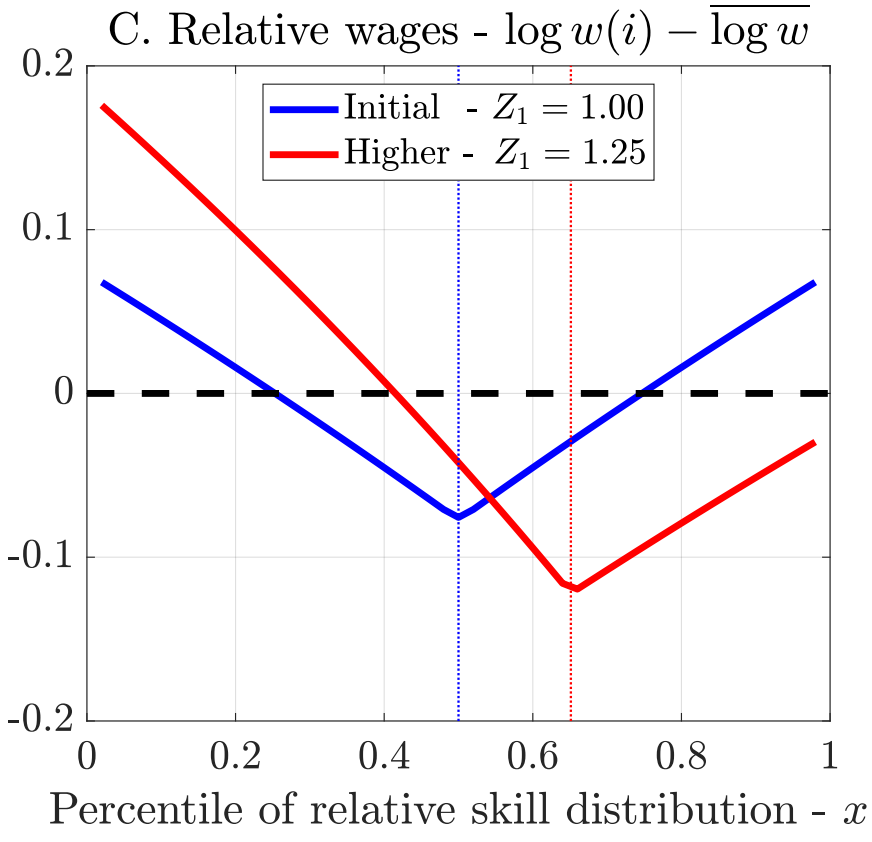
Other parameters: $\alpha_{1A} = \alpha_{2B} = 0.80$, $\sigma = 0.20$, $\theta = 2$, $\overline{L}_1 = \overline{L}_2 = 1$, $Z_2 = 1$.

Back - Comparative statics

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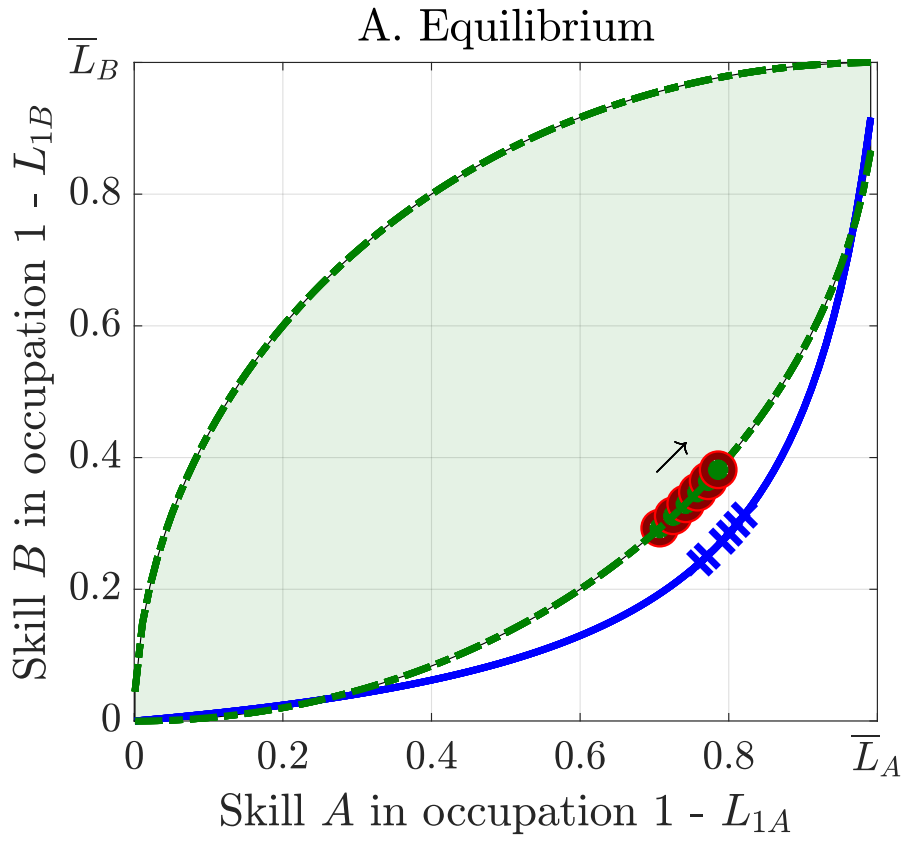


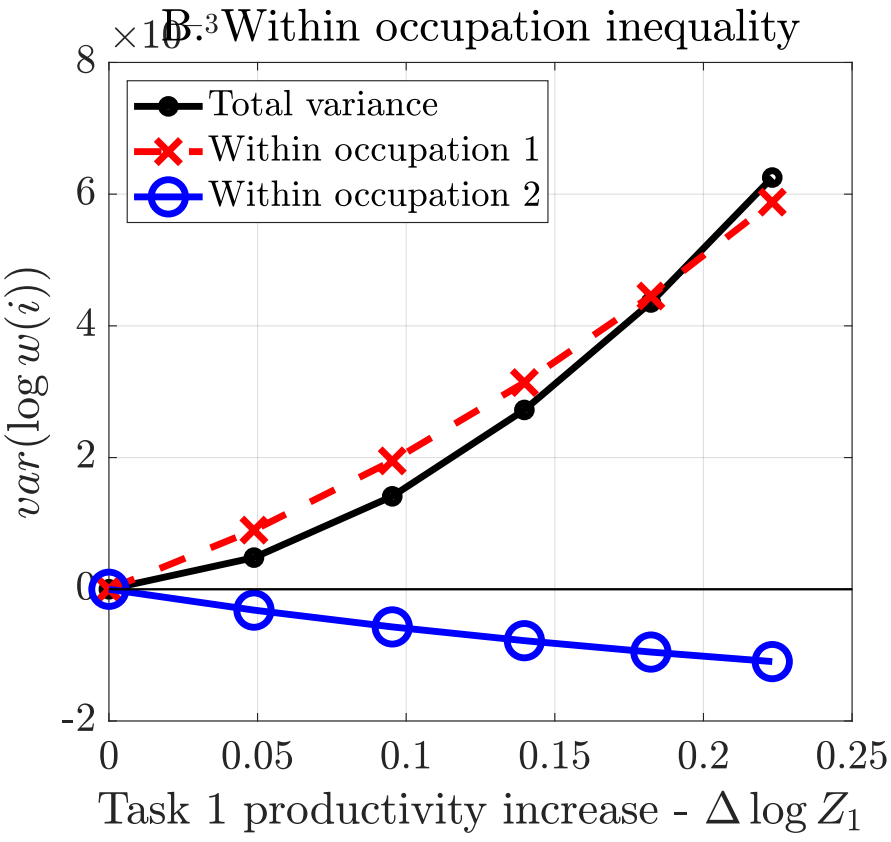
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Back - Comparative statics

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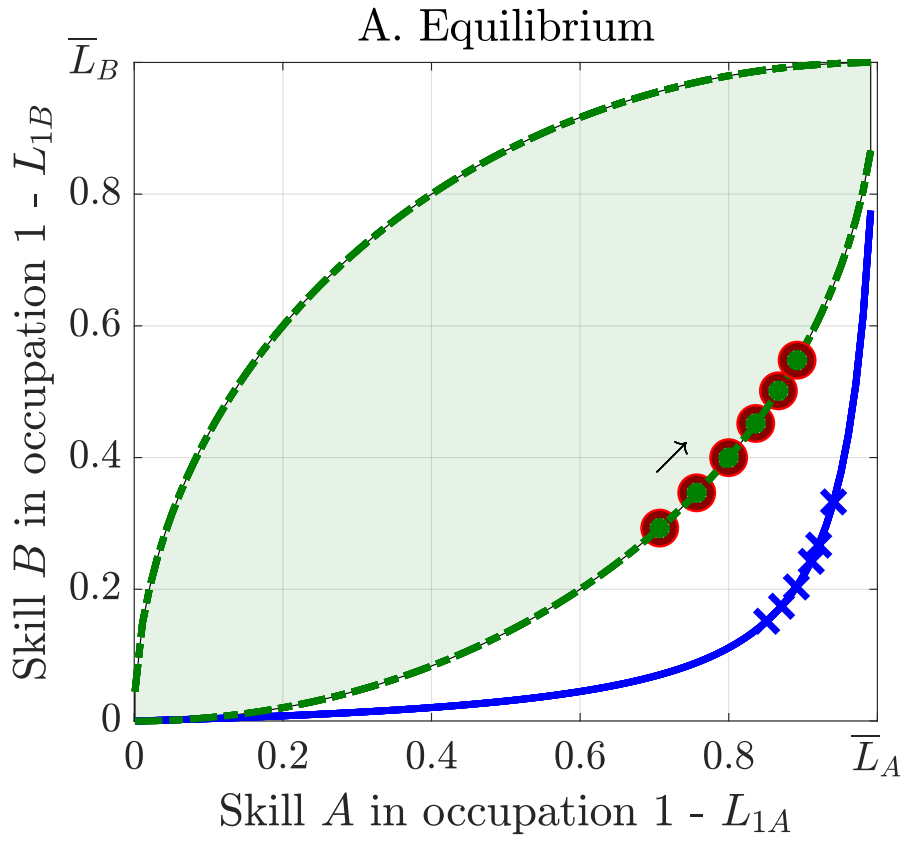


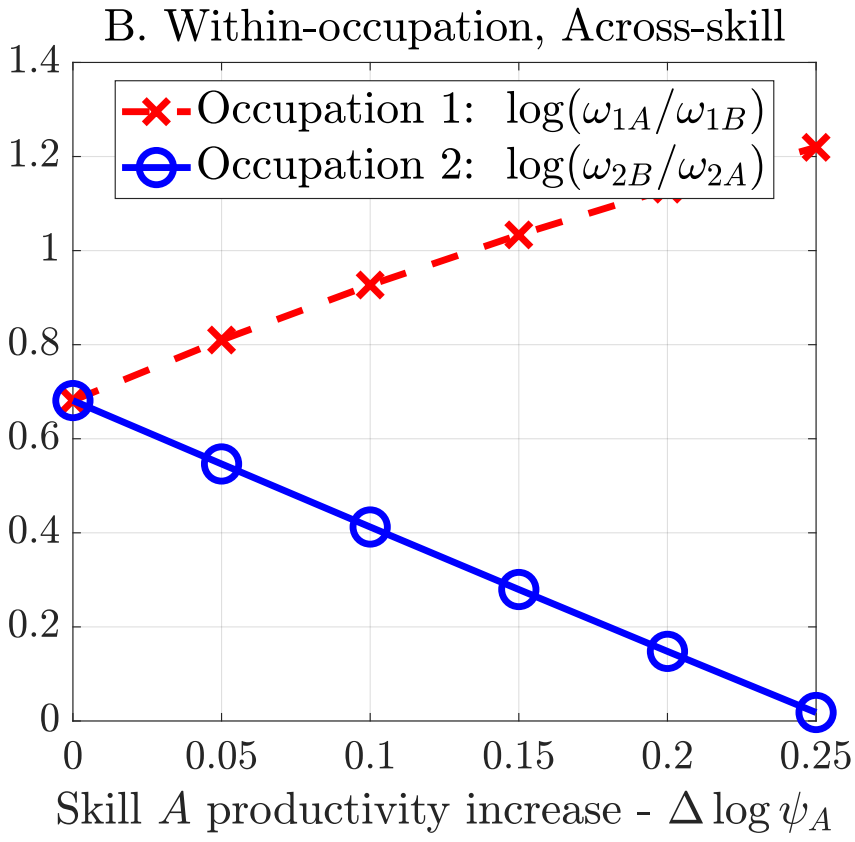
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Back - Comparative statics

3. Skill-Biased Change

Exogenous $\uparrow \psi_A$, with $\phi > 1$, $\sigma > 0$: $\uparrow Y_1$, $\downarrow Y_2$.
Marginal worker has more Skill B, pushes up ω_{1A}/ω_{1B}. Opposite for task 2.



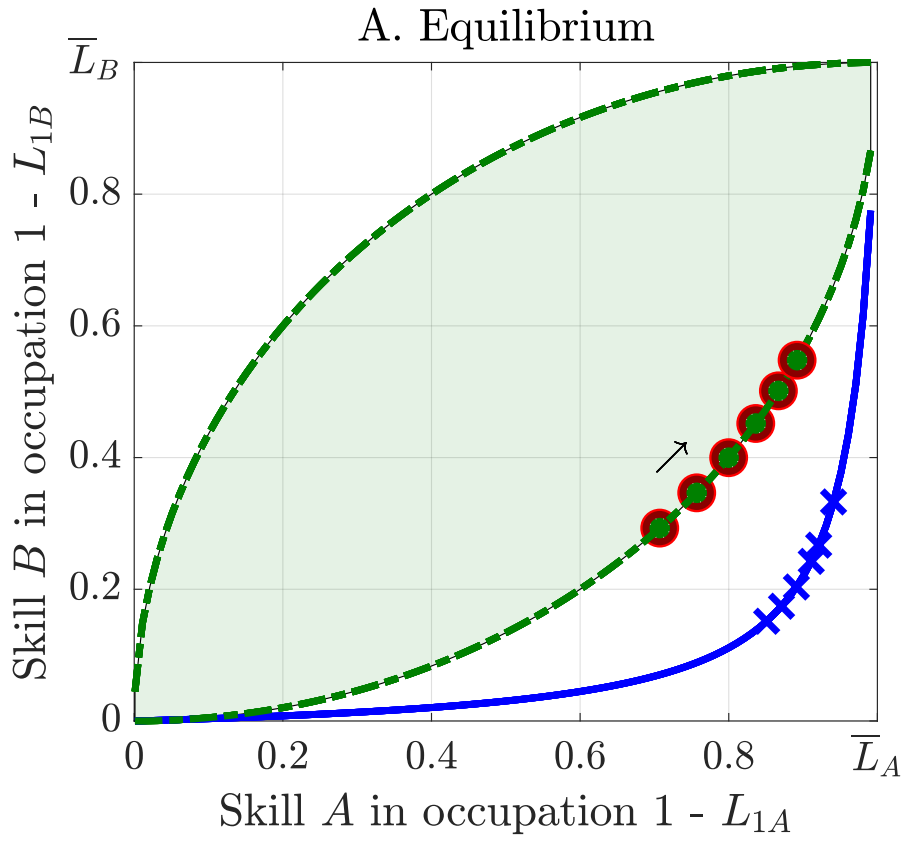


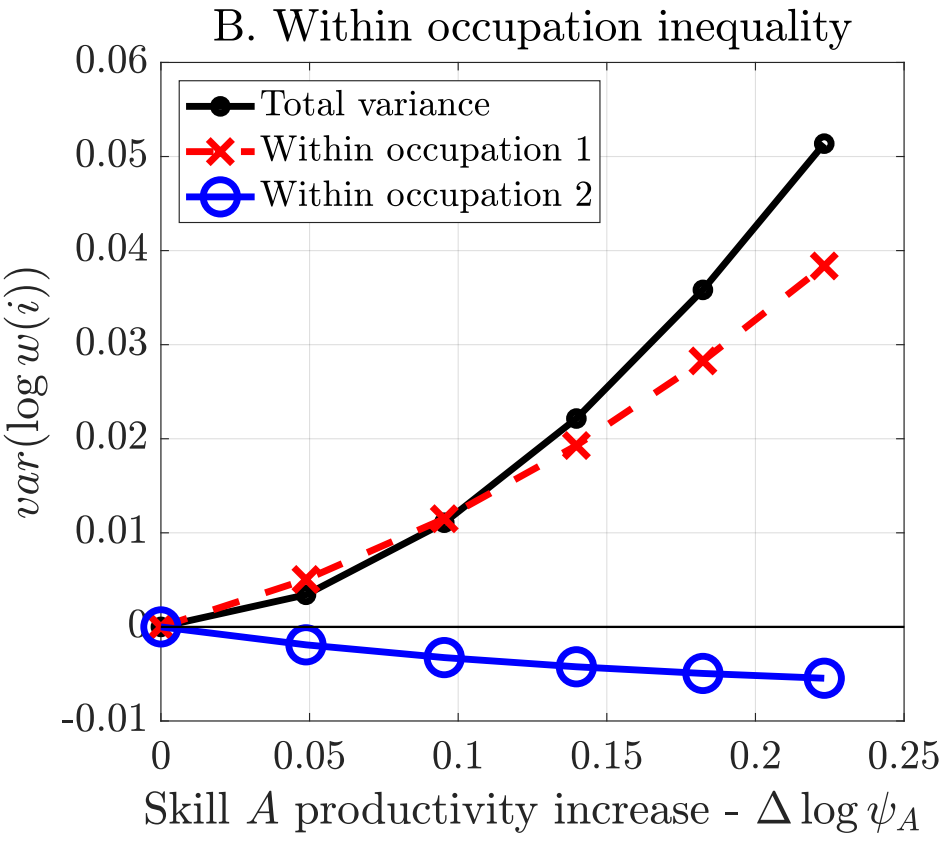
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Back - Comparative statics

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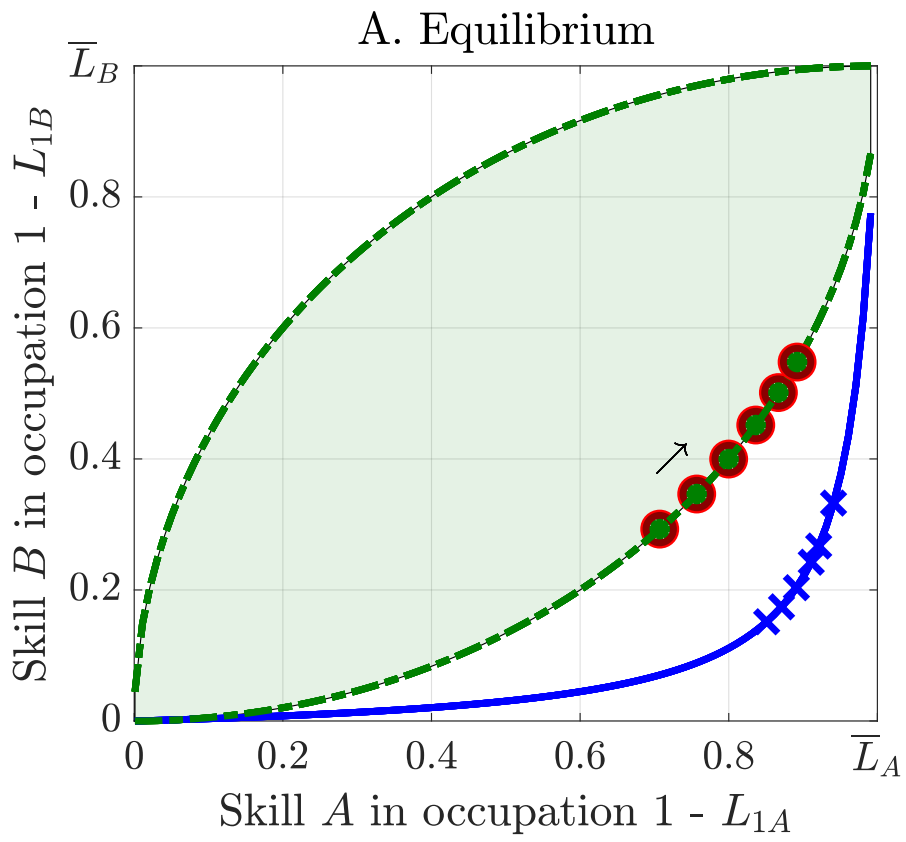


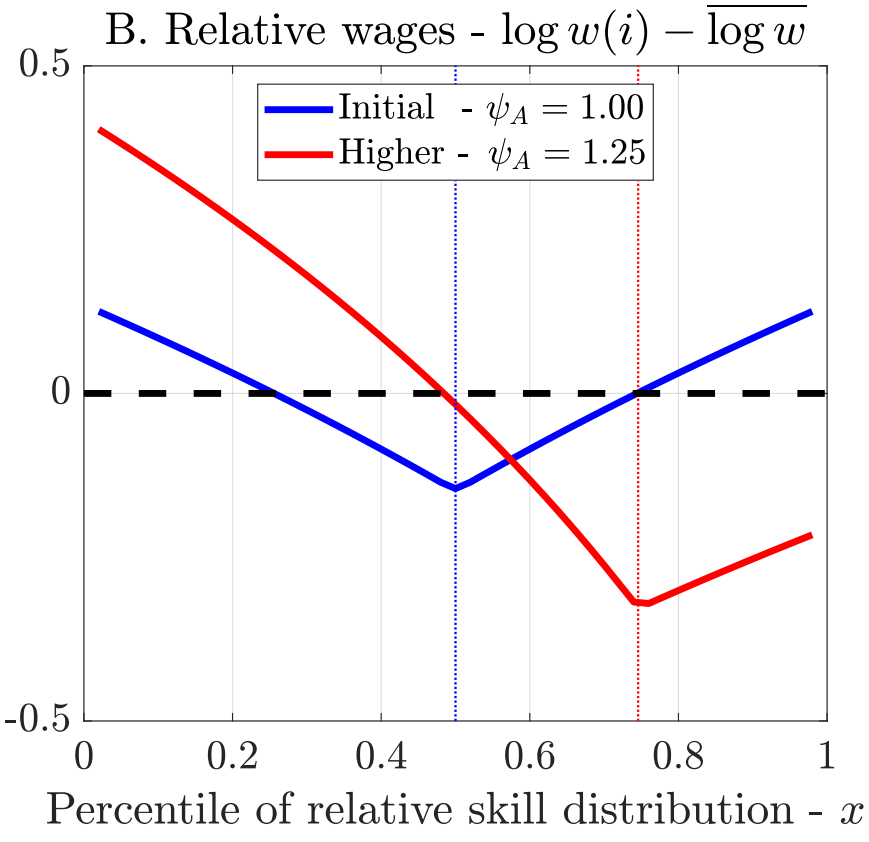
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Back - Comparative statics

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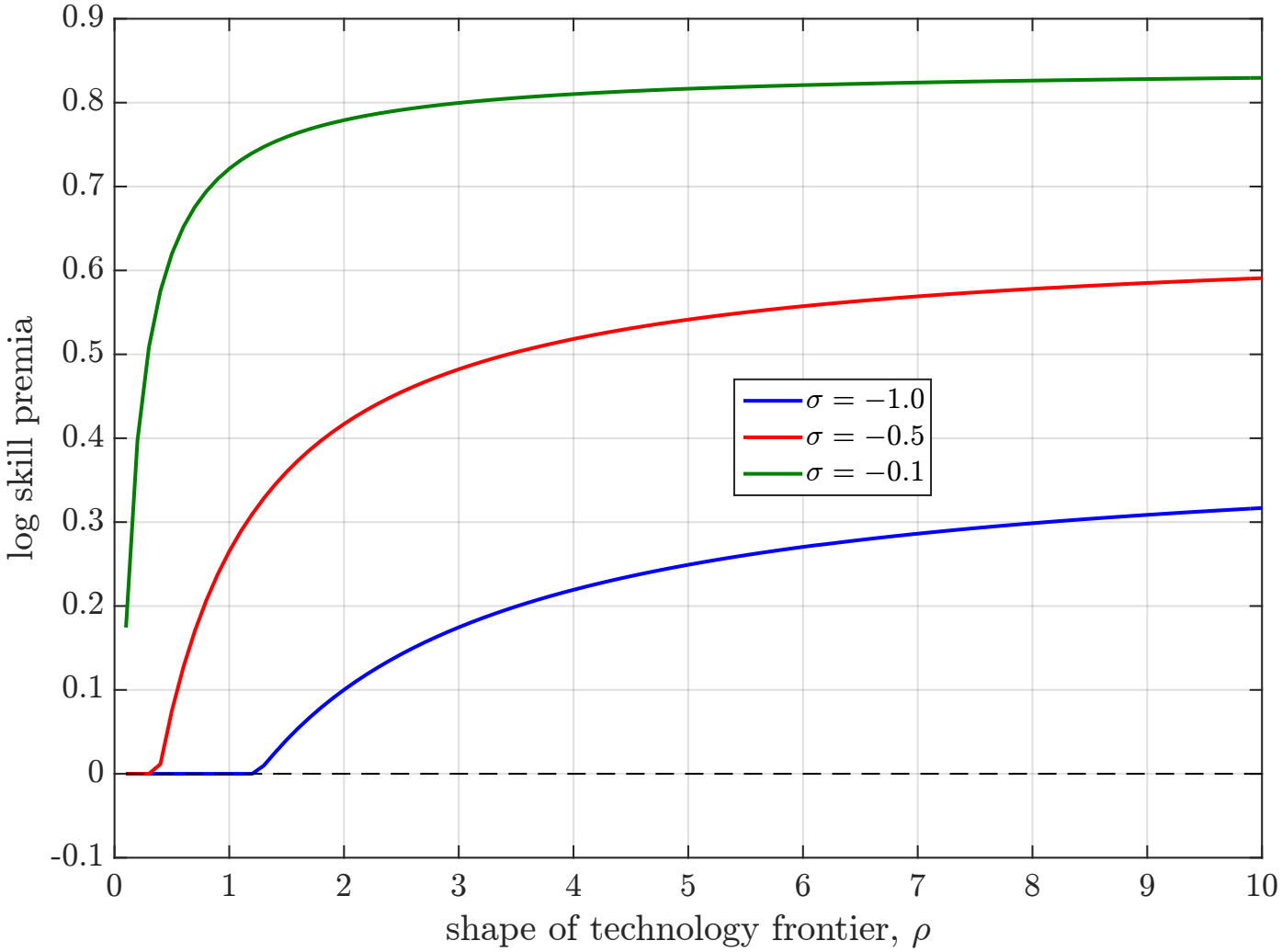


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Back - Comparative statics

Unbundling Labor: $\downarrow \rho$, $\sigma < 0$

As ρ falls, technologies become 'more substitutable'. If $\sigma < 0$, firms undo existing skill bias, bundling constraints loosen, skill premia fall, wage gains for generalists. $p_A = \omega_{1A} - \omega_{2A}$



Extensions I

- Absolute vs. comparative advantage

$$\left(l_1, l_2\right) = \left(\psi, \psi x\right) \quad , \quad \left(\psi, x\right) \sim H\left(\psi, x\right)$$

  + fixed utility of being out of the labor market

- Selection on *x margin* (occupation) and on *ψ margin* (participation)

- Result: Competitive equilibrium allocation is efficient

Extensions I

- Absolute vs. comparative advantage

$$\left(l_1, l_2\right) = \left(\psi, \psi x\right) \quad , \quad \left(\psi, x\right) \sim H\left(\psi, x\right)$$

  + fixed utility of being out of the labor market

- Selection on *x margin* (occupation) and on *ψ margin* (participation)

- RESULT: Competitive equilibrium allocation is efficient

- What are the effects of adding a mass of *low-productivity unspecialized workers* ($\downarrow \psi$, $x \approx 1$)?

  (sr) wages and allocations for fixed technology

  (lr) wages and allocations for endogenous technology

Empirics - Details

- All data based on March CPS 'last year' questions
- Occupation, Industry - Dorn's 1990 harmonized cross-walk
  - Drop military
  - Occupation skill = Fraction of workers with high-school or less
  - Occupations sorted on occupation skill
- Use HPV (RED, 2010)
  - Earnings = Wage income + (2/3)× Self employment income
  - Annual hours = *Weeks worked last year* × *Usual hours worked per week*
  - Wage = Earnings / Annual hours
  - Age 25-65, Wage > 0.5× Federal minimum wage, Hours > One month of 8hr days
- Regression controls for residualized wage:
  - Worker education (3 levels), Industry (1 digit), Experience, Experience^2 Race, Log hours,
  - Experience = (age - max(years in school,12)) - 6

Back - Motivating empirics

Empirics - Regressions

1. Workers in low skill occupations getting paid more 'similarly'.
   - Reduced form empirical evidence from the CPS

$$\log Earnings_{i,t} = \gamma_t + \delta^{Occ}_{period} + \boldsymbol{\beta}'_{period}\mathbf{X}_{i,t} + \varepsilon_{i,t}$$

$$\mathbf{X}_{i,t} = \left[Year_t, NAICS1_{it}, Ed_{it}, Race_{it}, Sex_{it}, FirmSize_{it}, Exp_{it}, Exp^2_{it}, Hours_{it}\right]$$

   - Low skill: Decline in $\downarrow \widehat{\beta}_{period}$ for (i) experience, (ii) hours, (iii) large firm
   - High skill: No change

2. Anecdotal evidence from US labor market
   - Goldin Katz (2012) vs. David Weil (2014)
   - Hard to explain declining level of 'attachment' of working age men

▸ Back - Motivating empirics

Fact A. - Technology

- Input is a $J \times K$ normalized matrix of skill measures $\mathbf{A}$ from O*NET

1. Apply principal components with $K^* \ll K$

$$\mathbf{A}_{[J\times K]} = \widehat{\mathbf{A}}_{[J\times K^*]}\widehat{\mathbf{P}}_{[K^*\times K]} + \mathbf{U}_{[J\times K]}$$

2. To *name* skills, rotate principal components s.t. satisfy K^* orthogonality conditions

$$\mathbf{A}_{[J\times K]} = \left(\widehat{\mathbf{A}}_{[J\times K^*]}\Psi\right)\left(\Psi^{-1}\widehat{\mathbf{P}}_{[K^*\times K]}\right) + \mathbf{U}_{[J\times K]} \;\rightarrow\; \mathbf{A}^* = \widehat{\mathbf{A}}\Psi$$

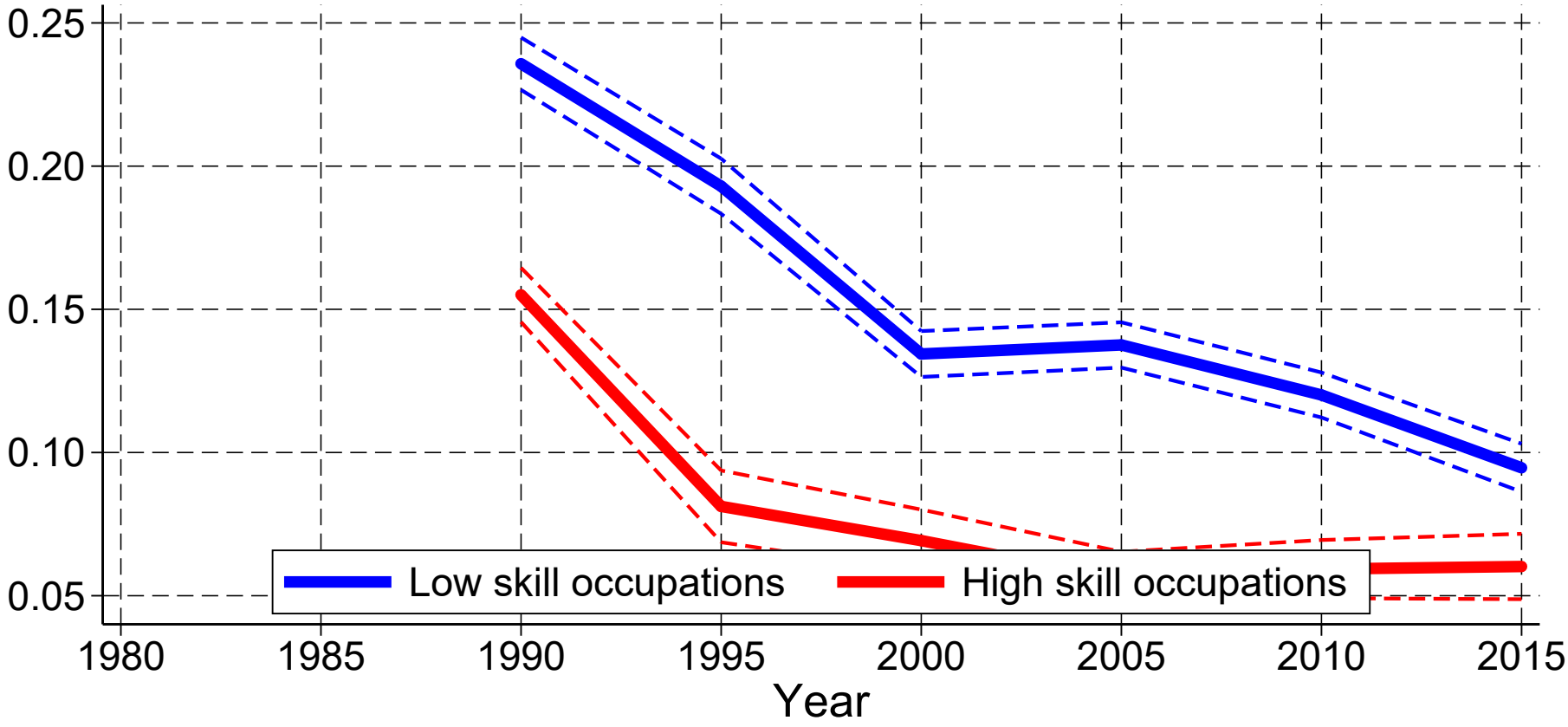
$\Longrightarrow$ Final skill 1, places a weight of 1 on $k = 1$, and zero on $k \in \{2, \ldots, K^*\}$

3. Use as K^* 'anchoring' skills those used by Acemoglu Autor (2011)

- Non-routine cognitive: Analytical - "Analyzing data / information"
- Non-routine cognitive: Interpersonal - "Maintaining relationships"
- Routine cognitive - "Importance of repeating the same tasks"
- Routine manual - "Controlling machines and processes"

Back - Fact B. Technology

Decreasing size premium in low skill occ

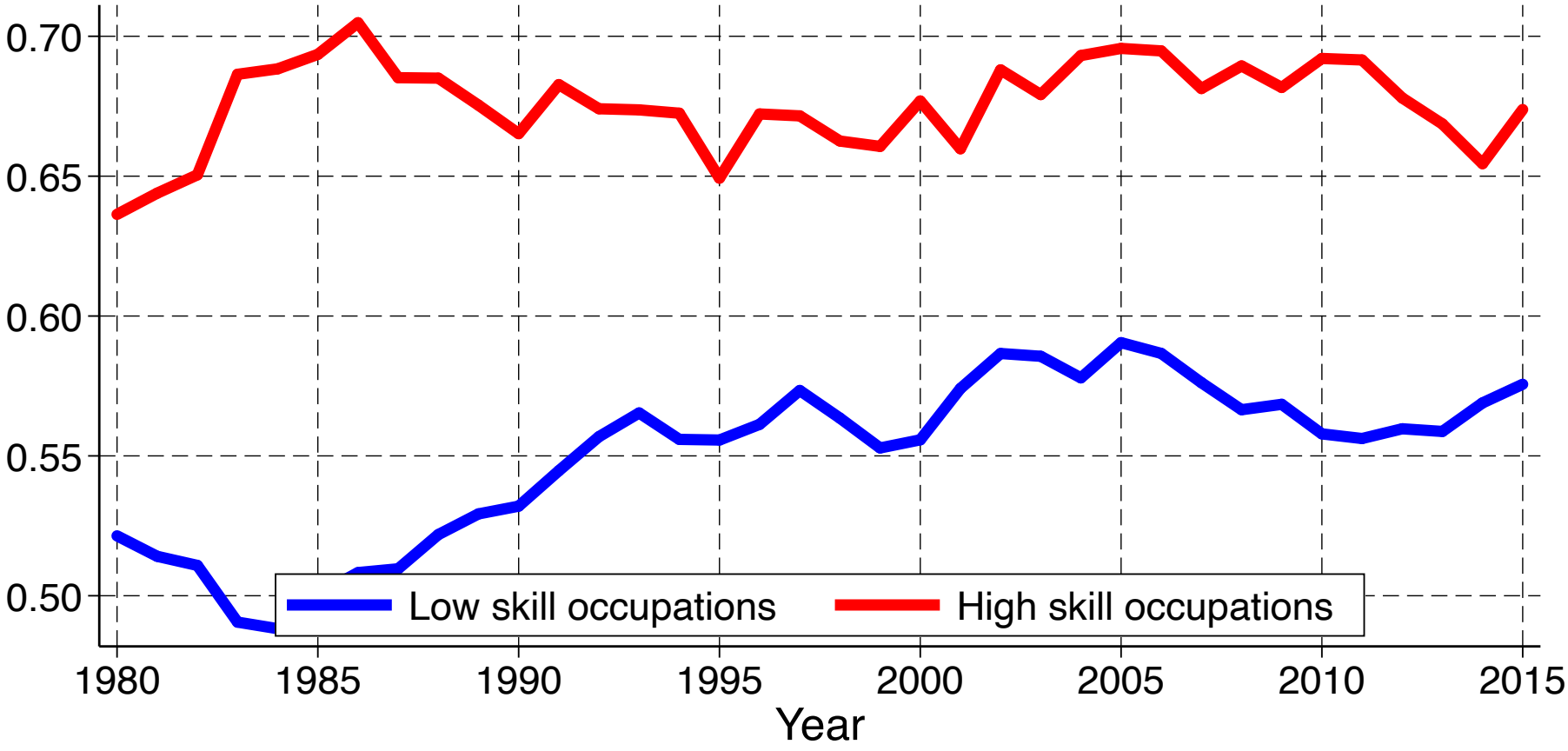


1000+ employee firms associated with a 10 to 15 percent premium

$$\log Inc_{it} = \alpha + \beta^{\tau}_{Hours} \log Hours_{it} + \beta^{\tau}_{Exp} Exp_{it} + \beta^{\tau}_{Exp^2} Exp^2_{it} + \beta^{\tau}_{Size} Size_{it} \ldots + \beta^{\tau}_{X} \left[Year_t, Race_{it}, NAICS1_{it}, Ed_{it}, Sex_{it}\right]$$

Back - Motivating empirics

Increasing switching in low skill occ

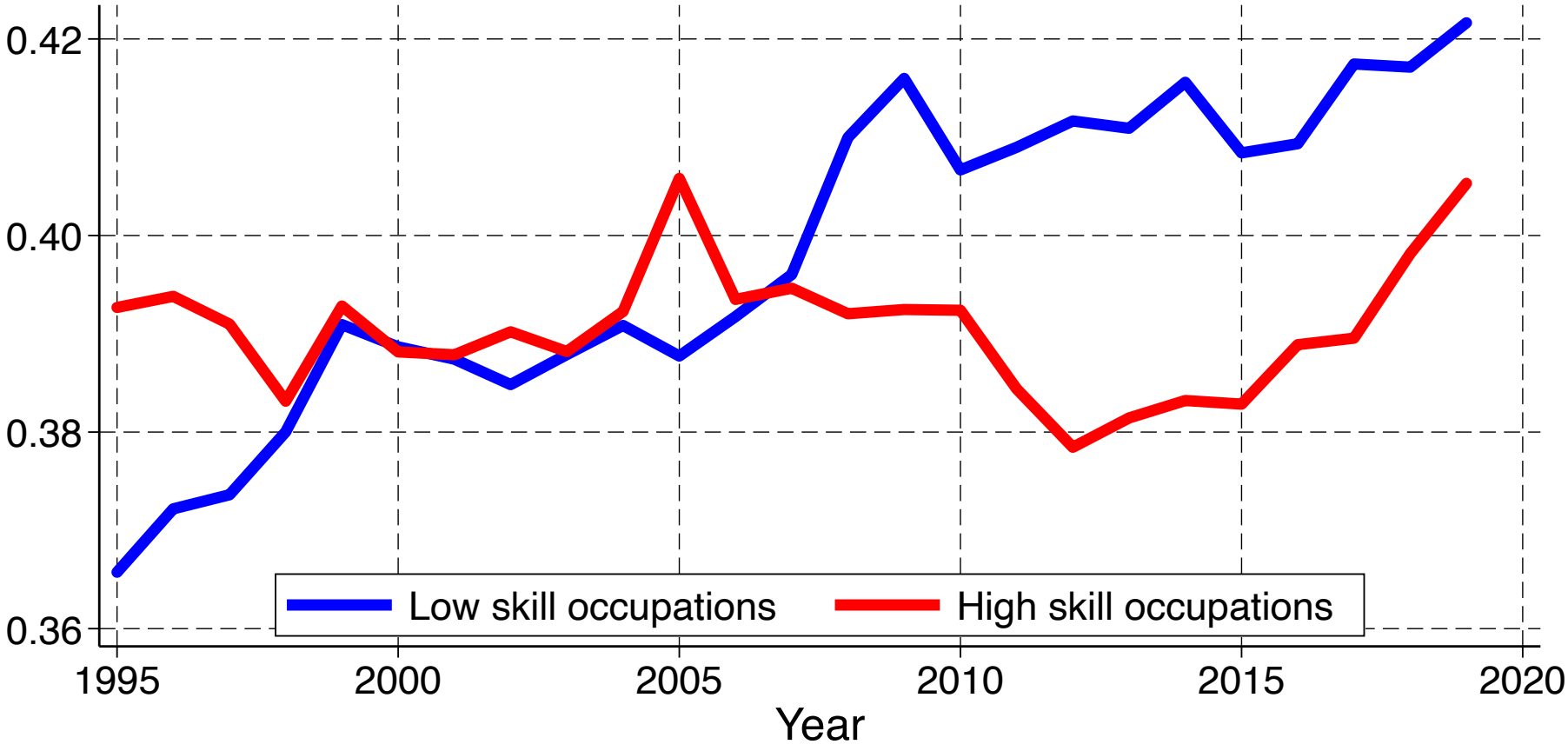


Fraction of **male** workers experiencing $\left\{E_{March}, \ldots, U_m, \ldots, E_{March'}\right\}$

that swap **3-digit** occupations across $\left\{E_{March}, E_{March'}\right\}$

Back - Motivating empirics

Increasing switching in low skill occ

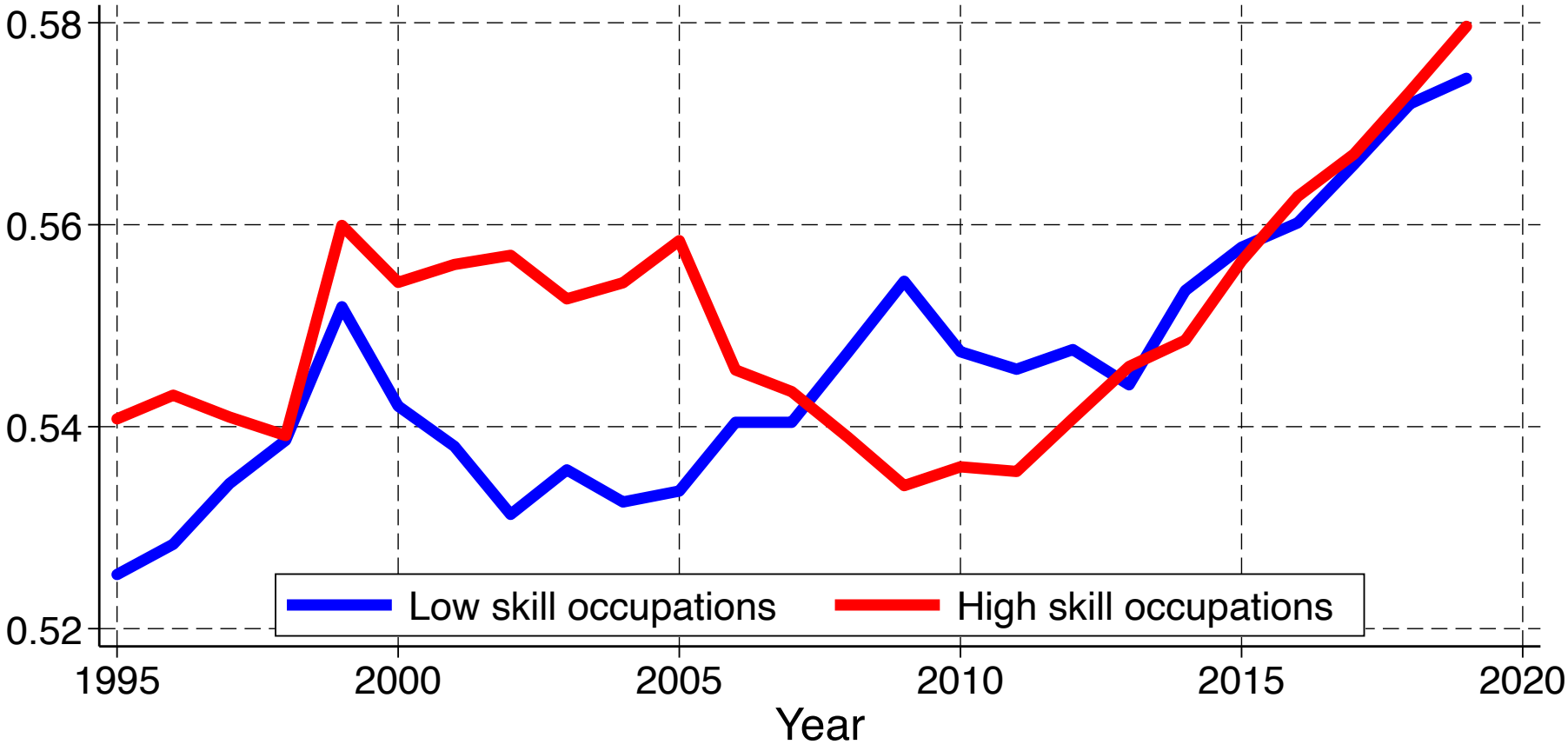


Fraction of **male** workers experiencing $\left\{E_{Month}, E_{Month+1}\right\}$

that swap **1-digit** occupations across $\left\{E_{Month}, E_{Month+1}\right\}$

Back - Motivating empirics

Increasing switching in low skill occ



Fraction of **male** workers experiencing $\left\{E_{Month}, E_{Month+1}\right\}$

that swap **3-digit** occupations across $\left\{E_{Month}, E_{Month+1}\right\}$

Back - Motivating empirics