Wage Gaps and Directed Technical Change

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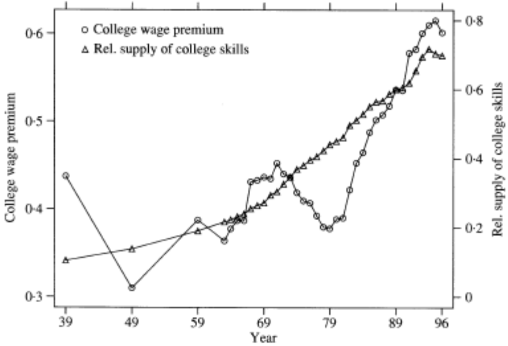
Gender-biased technical change?

- Common narrative: technology has replaced male labor more than female labor
  - Jobs in manufacturing reduced in part because of technology
- Usual reasoning: tasks that women do are harder to replace with technology
  - cognitive vs. manual, non-routine vs. routine
  - brains vs. brawn, people vs. things
- Additional force: directed technical change
  - men were more expensive than women, so more reward to innovating to replace them
  - women were discriminated against
- Similar forces from unionization
  - Causal evidence more likely here

Big Picture: Directed Technical Change

- Big idea: the direction of innovation is endogenous
  - Price effect: develop tech used in production of more expensive goods (or using more expensive factors)
  - Market size effect: develop tech with larger market, i.e. using more abundant factor
- Can create upward sloping labor (or any factor) demand curve



Relative Supply of College Skills and College Premium

Cross-Sectional Evidence: Gender, Unionization, and Innovation

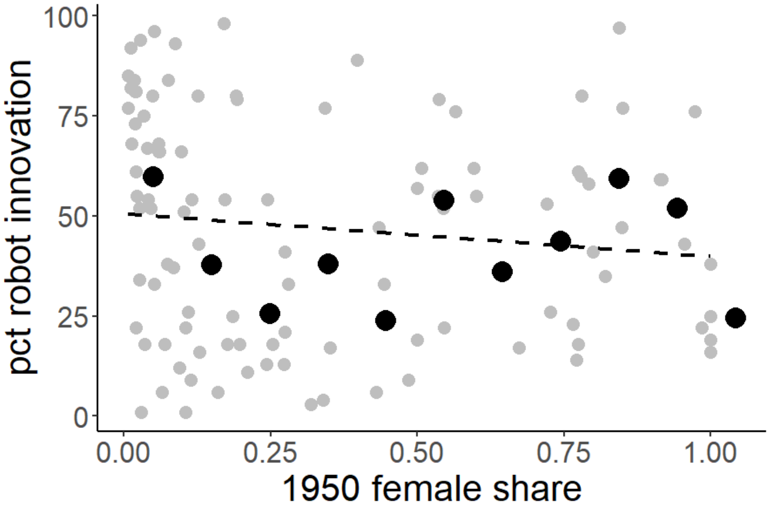
Data: innovation, female shares, unionization

- Webb (2020) measure of patent overlap with occupational tasks from O*NET
  - Verb-noun pairs indicate overlap
  - For robots, software, and AI; each occupation gets a "prevalence score" based on how many patents have text overlapping with the job tasks
    - I use percentiles of occupation's overlap score
  - Use David Dorn's time-consistent *occ1990dd*

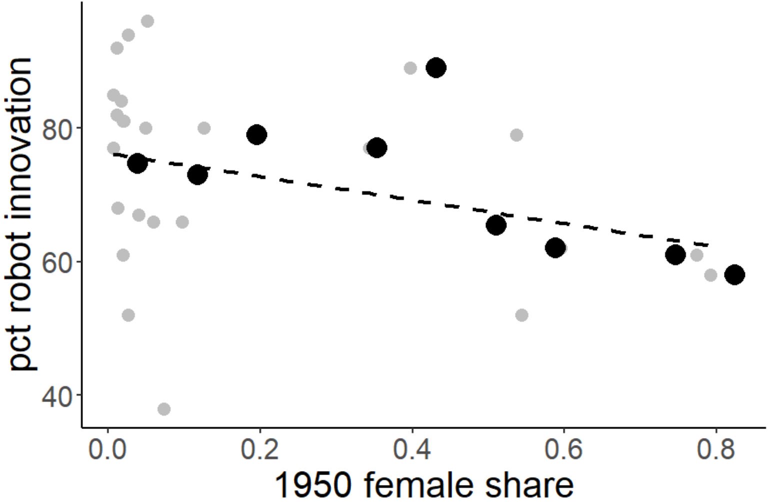
- Occupational female shares from census

- Unionization from CPS merged outgoing rotation groups
  - Compiled by Hirsch and Macpherson at `http://unionstats.gsu.edu/`
  - Use share of occupational employees who are union members

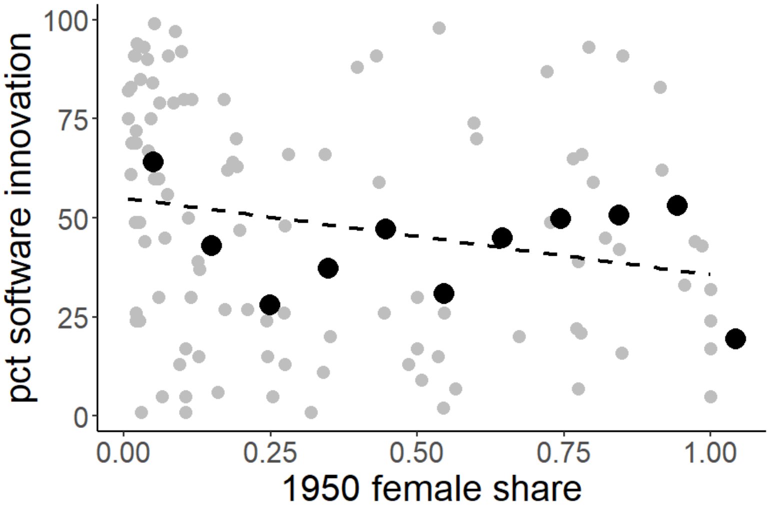
More female jobs experienced less robot innovation



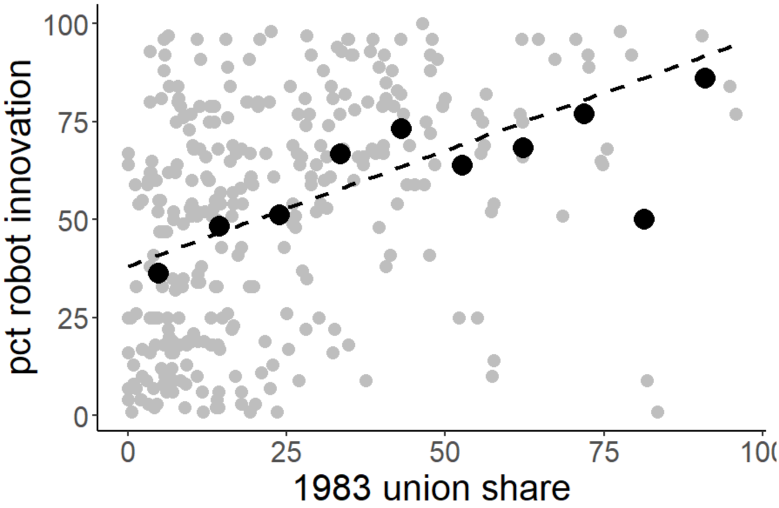
More female jobs experienced less robot innovation
Even limited to production jobs



More female jobs experienced less software innovation



More unionized jobs experienced more robot innovation



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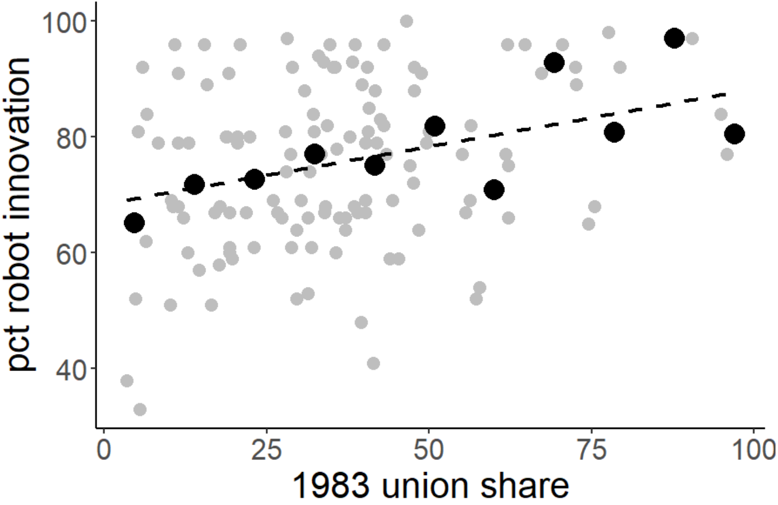

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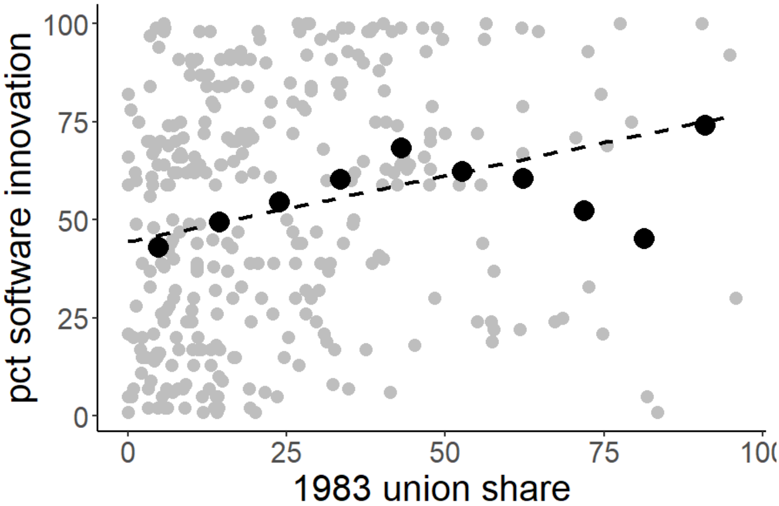


Isolating a causal channel

- Cross-sectional evidence shows more male, more unionized occupations experienced more innovation

- But does male share, unionization *cause* innovation?

- Unionization:
  - Does timing of unionization predict technical innovation in an occupation?
  - Does more innovation follow if a union forms in a close election?
  - Alternatively, does technology takeup increase in a firm when workers unionize?

- Gender:
  - Causal channel harder to isolate
  - Consider closely related occupations: janitor vs. maid? Medical specialties?
  - If tasks are similar, is there more innovation/adoption in the male version of the task?

Biased Technical Change: Acemoglu (2002)

Factor-Augmenting and Factor-Biased Technical Change

- Aggregate production function $F(L, Z, A)$
  - L labor, Z other input, A technology
  - $\partial F / \partial A > 0$
- *L-augmenting* technical change:

$$F(AL, Z)$$

- *L-biased* technical change:

$$\frac{\partial \frac{\partial F/\partial L}{\partial F/\partial Z}}{\partial A} > 0$$

  - Increasing A increases the relative marginal product of L

A Concrete Example: CES Production Function

$$y = \left[\gamma (A_L L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(A_Z Z)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

- elasticity of substitution $\sigma \in (0, \infty)$
  - $\sigma \to \infty$ perfect substitutes, $\sigma = 0$ perfect complements, $\sigma = 1$ Cobb-Douglas
  - $\sigma > 1$ gross substitutes, $\sigma < 1$ gross complements
- A_L is *L-augmenting*, A_Z is *Z-augmenting*
- Whether technical change is *L-biased* or *Z-biased* depends on elasticity of substitution

Elasticity of Substitution Determines Bias

- Relative marginal product of Z

$$\frac{MP_Z}{MP_L} = \frac{1-\gamma}{\gamma}\left(\frac{A_Z}{A_L}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{Z}{L}\right)^{-\frac{1}{\sigma}}$$

$\frac{MP_Z}{MP_L}$ is decreasing in Z/L: usual substitution effect

- Effect of A_Z on $\frac{MP_Z}{MP_L}$ depends on σ:

Gross substitutes ($\sigma > 1$)

  - increase in $\frac{A_Z}{A_L}$ increases $\frac{MP_Z}{MP_L}$
  - Z-augmenting change is Z-biased

Gross complements ($\sigma < 1$)

  - increase in $\frac{A_Z}{A_L}$ reduces $\frac{MP_Z}{MP_L}$
  - Z-augmenting change is L-biased

Intuition: with gross complements, increase in productivity of Z increases demand for other factor by more than demand for Z

Result overview

- Relative profitability of developing Z-augmenting technology will be proportional to

$$\left(\frac{A_Z}{A_L}\right)^{-\frac{1}{\sigma}}\left(\frac{Z}{L}\right)^{\frac{\sigma-1}{\sigma}}$$

- When $\sigma > 1$ (gross substitutes), increase in Z/L will increase relative profitability of inventing Z-augmenting technology
- When $\sigma < 1$ (gross complements), increase in Z/L will reduce relative profitability of inventing Z-augmenting technology, so A_Z/A_L will fall
  - But, when $\sigma < 1$, lower A_Z/A_L corresponds to Z-biased technical change, so relative value of marginal product of Z still increases

General Equilibrium with Endogenous Innovation: Directed Technical Change

Full Model Environment (Acemoglu, 2002)

- Representative consumer with CRRA preferences

$$\int_0^\infty \frac{C(t)^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt$$

- Budget constraint

$$C + I + R \leq Y \equiv \left[\gamma Y_L^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma) Y_Z^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

- Production functions for two goods:

$$Y_L = \frac{1}{1-\beta} \left(\int_0^{N_L} x_L(j)^{1-\beta} dj \right) L^\beta$$

$$Y_Z = \frac{1}{1-\beta} \left(\int_0^{N_Z} x_Z(j)^{1-\beta} dj \right) Z^\beta$$

- N_L, N_Z range of machines used by L, Z

Demand Side for Ideas: Profits

- Present value of profits to technology monopolists (on BGP):

$$V_L = \frac{\beta {p_L}^{1/\beta} L}{r} \qquad V_Z = \frac{\beta {p_Z}^{1/\beta} Z}{r}$$

- Price effect: greater incentive to invent technologies producing more expensive goods (V_L and V_Z increasing in p_L and p_Z)

- Market size effect: a larger market for technology leads to more innovation. Market is the workers who use it. Encourages innovation for the more abundant factor. (V_L and V_Z increasing in L and Z)

- Increase in relative factor supply Z/L will create both a market size and a price effect

- Equilibrium bias in technical change is determined by these two opposing forces

Price, Market Size, and Elasticity of Substitution

- Relative profitability as a function of relative technology

$$\frac{V_Z}{V_L} = p^{1/\beta}\frac{Z}{L} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{\sigma}} \left(\frac{N_Z}{N_L}\right)^{-\frac{1}{\sigma}} \left(\frac{Z}{L}\right)^{\frac{\sigma-1}{\sigma}}$$

- $\sigma \equiv \varepsilon - (\varepsilon - 1)(1-\beta)$ is elasticity of substitution between Z and L ($\sigma > 1$ iff $\varepsilon > 1$)
- Increase in relative factor supply Z/L
  - increases V_Z/V_L if $\sigma > 1$ (market size effect dominates)
  - decreases V_Z/V_L if $\sigma < 1$ (price effect dominates)
- Role of elasticity of substitution in relative factor rewards

$$\frac{w_Z}{w_L} = p^{\frac{1}{\beta}}\frac{N_Z}{N_L} = \left(\frac{1-\gamma}{\gamma}\right)^{\frac{\varepsilon}{\sigma}} \left(\frac{N_Z}{N_L}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{Z}{L}\right)^{-\frac{1}{\sigma}}$$

- If $\sigma > 1$, greater N_Z/N_L increases w_Z/w_L, otherwise no
- Z-biased technical change corresponds to an increase in $(N_Z/N_L)^{\frac{\sigma-1}{\sigma}}$

Supply of Innovation - Lab Equipment Model

Production function for new machine varieties

$$\dot{N}_L = \eta_L R_L \qquad \dot{N}_Z = \eta_Z R_Z$$

R_L: spending on R&D for L-intensive good (in terms of final good)

η_L and η_Z allow the costs of the two types of innovation to differ

For BGP with innovation in both sectors, need technology market clearing condition:

$$\eta_L \pi_L = \eta_Z \pi_Z$$

Solve to get

$$\frac{N_Z}{N_L} = \eta^{\sigma} \left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon} \left(\frac{Z}{L} \right)^{\sigma - 1}$$

Weak Induced Bias Hypothesis

$$\frac{N_Z}{N_L} = \eta^{\sigma} \left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon} \left(\frac{Z}{L} \right)^{\sigma - 1}$$

Relative level and bias of technology determined by relative factor supply and elasticity of substitution

Gross substitutes ($\sigma > 1$)

- increase in Z/L raises N_Z/N_L - physical productivity of abundant factor tends to be higher.
- Higher level of N_Z/N_L corresponds to Z-biased technical change.
- Technology endogenously biased in favor of more abundant factor

Gross complements ($\sigma < 1$)

- N_Z/N_L is lower when Z/L is higher.
- But lower relative physical productivity still translates into higher value of MP because $\sigma < 1$!
- Technology still endogenously biased in favor of more abundant factor - weak induced bias hypothesis

Strong Induced Bias Hypothesis

Factor Prices

$$\frac{w_Z}{w_L} = \eta^{\sigma-1} \left(\frac{1-\gamma}{\gamma} \right)^{\varepsilon} \left(\frac{Z}{L} \right)^{\sigma-2}$$

Strong induced-bias hypothesis

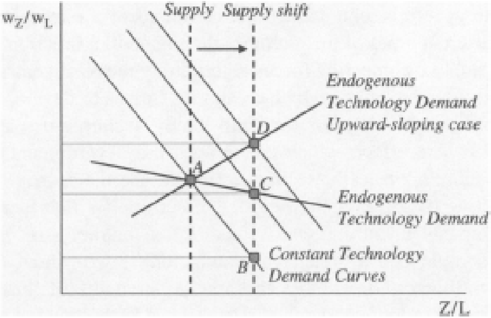
If σ is sufficiently large, ($\sigma > 2$), the relationship between relative factor supplies and relative factor rewards can be upward sloping

Intuition:

- Exogenous technology: when a factor becomes more abundant, its relative reward falls
- Endogenous technology: biased towards more abundant factors, so effect of factor abundance on factor rewards is ambiguous

Takeaways

- Direction of technical change determined by price effect and market size effect
- Weak induced-bias hypothesis
  - regardless of elasticity of substitution, an increase in relative abundance of a factor creates some amount of technical change biased toward that factor
- Strong induced-bias hypothesis
  - If the elasticity of substitution is particularly large, the induced bias in technology can make the relative demand curve for a factor slope up



Gender and directed technical change?

- What kind of gender bias in technical change does model predict?
  - Price effect: innovate more on male tasks because men are more expensive
  - Market size effect: innovate more on male tasks because there were more men in paid labor force
  - Price and market size effect suggest more development of male-augmenting technology in the past

- As female labor becomes more abundant, weak-induced bias hypothesis tells us there should be female-biased technical change
  - If $\sigma > 1$ (gross subs), innovation in female-augmenting technologies that is female-biased
  - If $\sigma < 1$ (gross comps), innovation in male-augmenting technologies that is female-biased
  - estimates suggest $\sigma > 1$, but this is for male and female labor directly, more concerned with tasks here

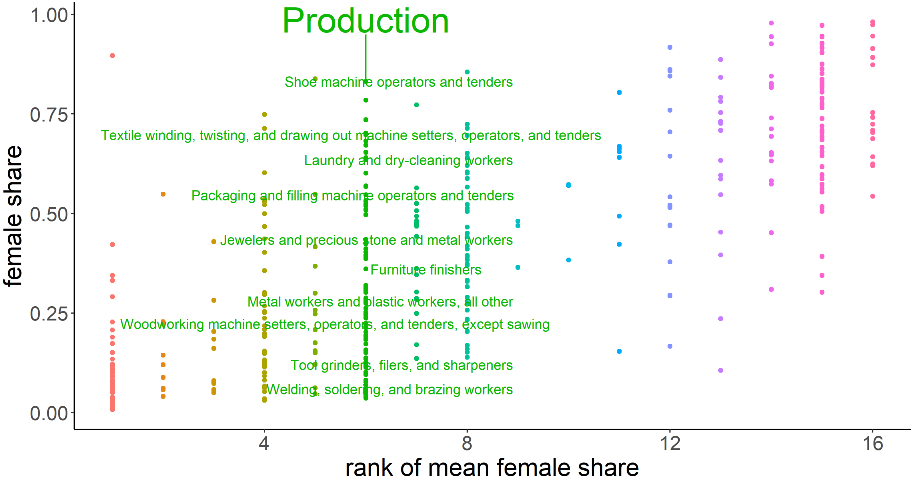
Conclusion and Next Steps

Summary and next steps

- Direction of technical change is endogenous
  - innovators respond to price effect and market size effect
- Cross-sectional evidence shows more innovation in more male, more unionized jobs
  - Holds even within production jobs
- Do gender and unionization wage gaps *cause* innovation?
  - Unions: timing of elections and innovation, adoption
  - Gender: similar tasks across different occupations

Appendix

Female Shares across Production Occupations



Supply of Innovation - Knowledge-Based R&D

Technology accumulation:

$$\dot{N}_L = \eta_L N_L^{(1+\delta)/2} N_Z^{(1-\delta)/2} S_L \qquad \dot{N}_Z = \eta_Z N_Z^{(1+\delta)/2} N_L^{(1-\delta)/2} S_Z$$

δ measures degree of state-dependence

Dynamics can be unstable when $\sigma > 1/\delta$

Greater N_Z/N_L creates usual market size and price effects but also affects relative costs of future R&D

If δ sufficiently high, latter effect becomes more powerful and creates destabilizing influence

For $\delta < 1$, conclusions in lab equipment specification still apply

If $\delta = 1$, to have innovation in both sectors, technical change acts to equate relative factor shares