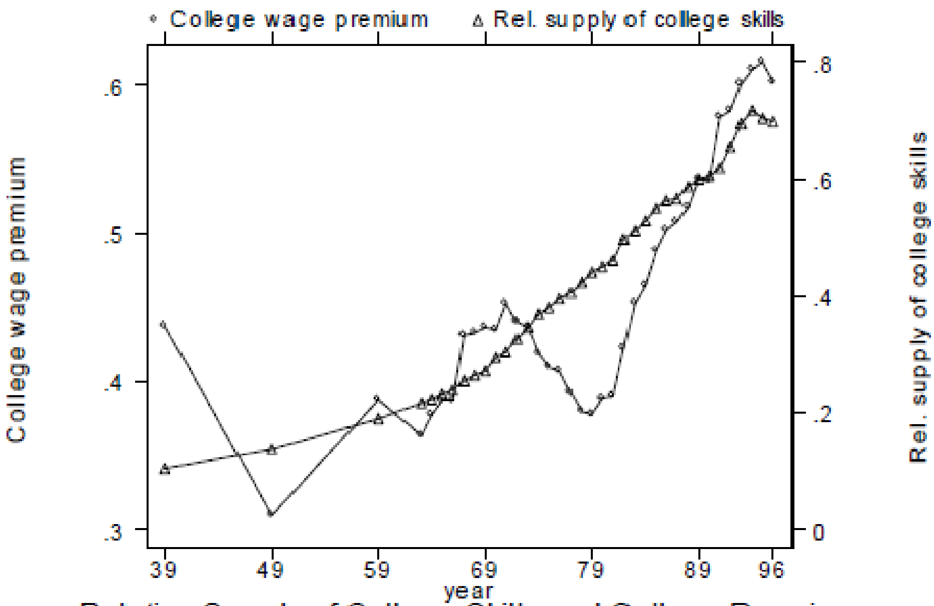
May 13, 2016

1 Goldin and Katz's (2009) model of the race between education and technology

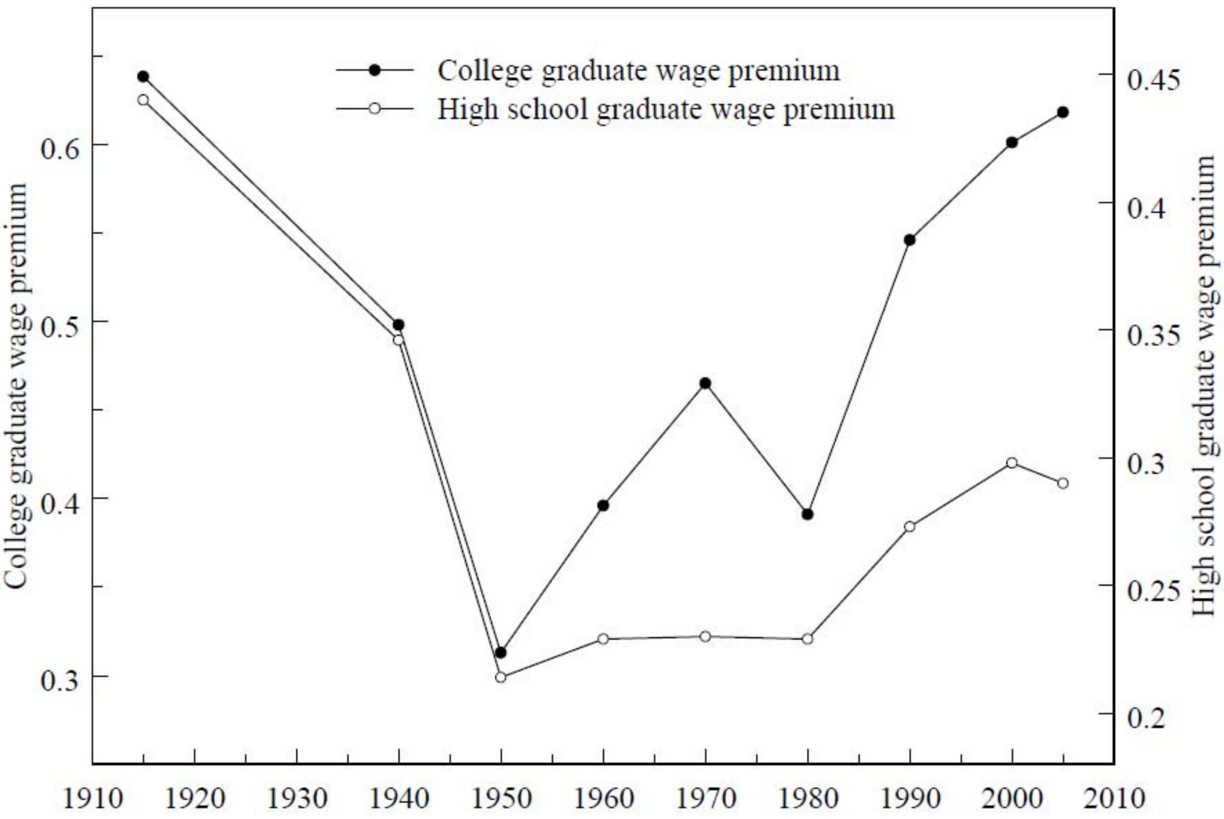


Relative Supply of College Skills and College Premium

Changes of the college wage premium and the relative supply of college-educated workers: USA 1915 – 2005 (annual log-changes x 100)

	Relative Wage	Relative Supply
1915-40	-0.38	5.54
1940-50	-1.32	4.38
1950-60	0.15	2.72
1960-70	0.01	5.31
1970-80	-0.01	5.65
1980-90	0.44	4.04
1990-2000	0.25	1.87
1990-2005	0.11	1.52

Source: Goldin and Katz (2009)



College graduate wage premium
High school graduate wage premium
College graduate wage premium
High school graduate wage premium
0.3
0.4
0.5
0.6
0.2
0.25
0.3
0.35
0.4
0.45
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

L = total supply of unskilled labor $\quad \mathcal{L}$ = set of unskilled workers
H = total supply skilled labor $\quad \mathcal{H}$ = set of skilled workers
$A_L L$ = efficiency units of unskilled labor
$A_H H$ = efficiency units of skilled labor

$$L = \int_{i \in \mathcal{L}} l_i \partial i \qquad H = \int_{i \in \mathcal{H}} h_i \partial i$$

CES production function

$$Y = [\theta (A_L L)^{\frac{\sigma-1}{\sigma}} + (1-\theta)(A_H H)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

$\sigma \in [0, +\infty) = |$*elasticity of substitution between H and L*$|$
Remark.
$\sigma = 1$ is the Cobb-Douglas production function
$\sigma = +\infty$ is the perfect-substitutes production function
$\sigma = 0$ is the Leontiev production function
sigma = d(log H/L)/ d(log MPL/PMH)= elasticity of substitution

- Factor augmenting technological progress
- Perfect competition in Y sector:

$$w_H = \frac{\sigma}{\sigma-1}[\theta(A_L L)^{\frac{\sigma-1}{\sigma}} + (1-\theta)(A_H H)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}-1} \cdot [(1-\theta)A_H{}^{\frac{\sigma-1}{\sigma}} H^{\frac{-1}{\sigma}}] \quad (2)$$

$$w_L = \frac{\sigma}{\sigma-1}[\theta(A_L L)^{\frac{\sigma-1}{\sigma}} + (1-\theta)(A_H H)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}-1} \cdot [\theta A_L{}^{\frac{\sigma-1}{\sigma}} L^{\frac{-1}{\sigma}}] \quad (3)$$

1.1 Predictions on wage levels

It can be verified that, except in the limiting cases $\sigma = 0$, and $\sigma = +\infty$, the following results hold:

$$\frac{\partial w_L}{\partial A_L} > 0; \quad \frac{\partial w_L}{\partial A_H} > 0$$

$$\frac{\partial w_H}{\partial A_H} > 0; \quad \frac{\partial w_H}{\partial A_L} > 0$$

Proposition 1 *A rise of the productivity levels A_H, A_L increases the wage rate for both types of workers.*

Intuition:

- A exogenous increase in the efficiency A_H of skilled labor increases the intensity of use of skilled, relative to unskilled labor.
- In this way, the marginal productivity of *unskilled* labor rises.
- After the change, the general wage level is therefore higher.

1.2 Predictions on the the wage ratio (skill premium)

$$\varpi = \frac{w_H}{w_L} = \frac{1-\theta}{\theta} \cdot \left(\frac{A_H}{A_L}\right)^{\frac{\sigma-1}{\sigma}} \cdot \left(\frac{H}{L}\right)^{\frac{-1}{\sigma}} \tag{4}$$

$$\ln \varpi = \text{ constant} + \frac{\sigma-1}{\sigma} \ln\left(\frac{A_H}{A_L}\right) - \frac{1}{\sigma} \ln\left(\frac{H}{L}\right) \tag{5}$$

Two forces in Tinbergen's (1974) model of skill-biased technological change:

1. evolution of $\frac{A_H}{A_L}$ reflects the skill bias of technology
2. evolution of $\frac{H}{L} \equiv X$ reflects the changes in the relative supply of skills

Differentiating (5) with respect to $\ln X$:

$$\frac{\partial \ln \varpi}{\partial \ln X} = -\frac{1}{\sigma}$$ = slope of relative demand for skills

Result 1.

- At given productivity ratio $\frac{A_H}{A_L}$ a larger relative supply of skilled labor lowers the skill premium, with elasticity $\frac{1}{\sigma}$.
- If the elasticity of substitution σ between skilled and unskilled labor is higher, the effect is lower.

Interpretation

- In the short run, the productivity ratio $\frac{A_H}{A_L}$ is fixed, and the relative demand curve for skills is downward sloping

if sigma is higher, the slope (in absolute value) is lower

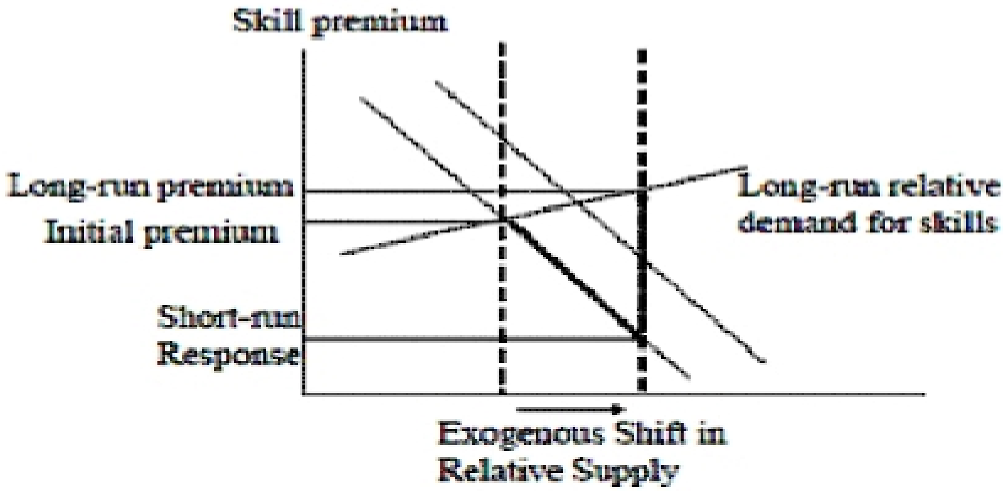
Differentiating (5) with respect to $\ln A_H/A_L$:

$$\frac{\partial \ln \varpi}{\partial \ln A_H/A_L} = \frac{\sigma - 1}{\sigma}$$

Result 2.

- At given relative supply $X \equiv \frac{H}{L}$ a larger relative productivity of skilled labor $\frac{A_H}{A_L}$ increases the skill premium, if elasticity of substitution $\sigma > 1$.

Interpretation: Rise of $\frac{A_H}{A_L}$ causes outward shift of the relative demand curve for skills. (on the hypothesis that elasticity of substitution sigma > 1)



Long-run demand for skills upward-sloping if:
1. sigma > 1
2. rise of AH/AL large enough relative to rise of H/L

Rise of $\frac{A_H}{A_L}$ may be explaind by:

- Exogenous factors: Historically contingent properties of technological trajectories (Goldin and Katz 2009)
- Endogenous factors: incentive based, directed technological change (Acemoglu 1998, Aghion 2002)

2 Exogenous explanation of rising $\frac{A_H}{A_L}$

One problem is that A_H and A_L are not directly observed. A strategy often used in the literature is to assume that the rate of skill-biased tecnical change is constant through time.

On the assumption that:

$$\ln \frac{A_{H,t}}{A_{L,t}} = \gamma_0 + \gamma_1 t \tag{6}$$

Recall equation (5):

$$\ln \varpi = \text{ constant } + \frac{\sigma - 1}{\sigma} \ln \left(\frac{A_H}{A_L} \right) - \frac{1}{\sigma} \ln \left(\frac{H}{L} \right) \tag{5}$$

Substitute for $\ln \frac{A_H}{A_L}$ in equation (5) from (6):

$$\ln \varpi = \text{ constant } + \frac{\sigma - 1}{\sigma} \cdot \gamma_0 + \frac{1}{\sigma} \left[(\sigma - 1)\gamma_1 t - \ln X_t \right]$$

$$\ln \varpi = \text{ constant} + \frac{\sigma - 1}{\sigma} \cdot \gamma_0 + \frac{1}{\sigma} \left[(\sigma - 1)\gamma_1 t - \ln X_t \right]$$

take the time derivative:

$$\frac{\dot{\varpi}_t}{\varpi_t} = \frac{1}{\sigma} \left[(\sigma - 1)\gamma_1 - \frac{\dot{X}_t}{X_t} \right]$$

γ_1 = growth rate of productivity ratio $\frac{A_H}{A_L}$

$(\sigma - 1)\gamma_1$ = *rate of skill-biased technical change = growth rate of the relative demand for skilled labor*

$\dot{X}_t / X_t$ = *growth rate of the relative supply* $\frac{H_t}{L_t}$ *of skilled labor*

Proposition 2 *If* $\sigma > 1$*, the skill premium* ϖ *increases, when the rate of skill-biased technical change is larger than growth rate of* $\frac{H_t}{L_t}$.

$$\ln \varpi = \textbf{constant} + \frac{(\sigma - 1)}{\sigma}\gamma_1 t - \frac{1}{\sigma}\ln\left(\frac{H_t}{L_t}\right) \tag{7}$$

OLS regression of equation (7) for 1963-1987 yields (Acemoglu Autor 2012):

$$\begin{array}{rcl} \ln \varpi & = & \textbf{constant} \; + \underset{(0.005)}{0.027} \cdot t - \underset{(0.128)}{0.612} \ln\left(\frac{H_t}{L_t}\right) \end{array}$$

- The estimated equation performs well in capturing the evolution of the college/high-school wage premium 1963-1987
- It predicts well the evolution of the college/high-school wage premium up to 1992
- From 1993 onwards the equation greatly overestimates the growth of the college/high-school wage premium

Good predictions of the Goldin and Katz frame work 1964 - 1992
Poor Predictions of the Goldin and Katz framework after 1992. Source Acemoglu and Autor (2012)

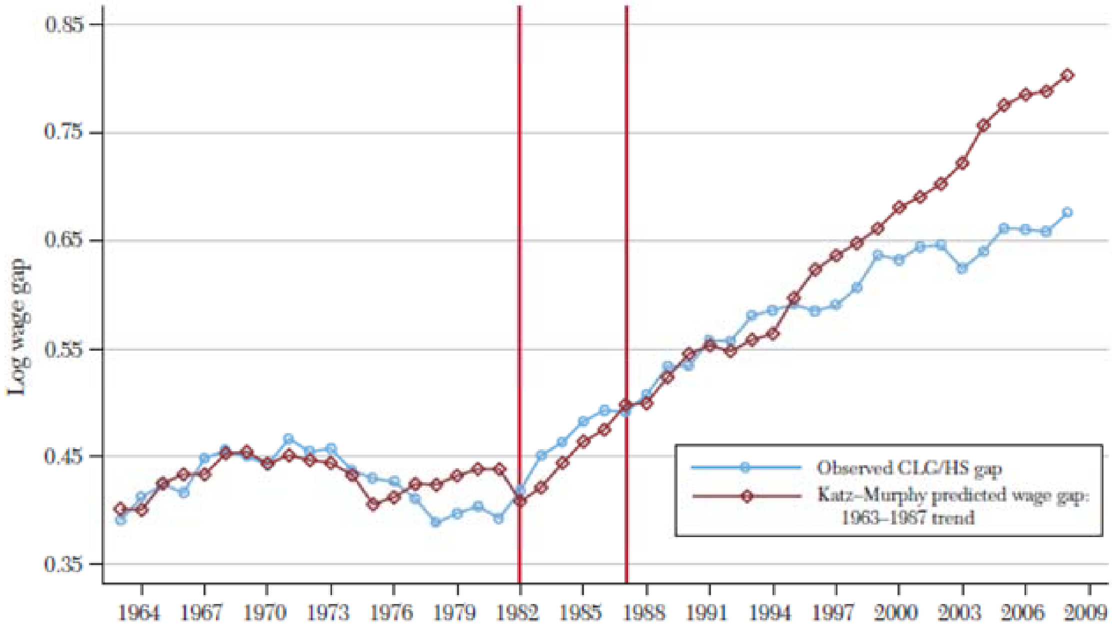


Figure 1. Katz–Murphy Prediction Model for the College–High School Wage Gap

3 Endogenous explanation of rising $\frac{A_H}{A_L}$

To simplify exposition we dispense with the CES production function, while retaining high substitutability between skilled and unskilled labor (see Aghion 2002).

$$Y = x_L + x_H \tag{8}$$

x_L = quantitity of intermediate good produced by unskilled labor
x_H = quantitity of intermediate good produced by skilled labor
x_L and x_H are perfect substitutes
S_L = supply unskilled labor
S_H = supply skilled labor

- Notice that the marginal productivity of both x_L and x_H is 1
- Firms in the Y sector are perfectly competitive
- this implies that the prices of x_L and x_H are

$$p_{xL} = p_{xH} = 1$$

Intermediate goods technology

$$x_L = A_L L^\alpha \tag{9}$$

$$x_H = A_H H^\alpha \tag{10}$$

where $0 < \alpha < 1$.

Endogenous technological progress

Simplifying Assumptions

- In each period t, 1 and only 1 firm invests in R&D a final output N_t in either sector L or H
- Monopoly rents from innovation last one period because innovations are imitated thereafter
- Total R&D investment N_t is devided between the two sectors according to:

$$N = n_{H,t} + n_{L,t}$$

- **Technology of R&D is deterministic:**

$$A_{H,t} = A_{H,t-1} n_{H,t}^{\beta} \tag{11}$$

$$A_{L,t} = A_{L,t-1} n_{L,t}^{\beta} \tag{12}$$

where $0 < \beta < 1$.

- **Monopoly profit maximazation:**
- In each sector $j = L, H$ monopoly power is constrained by the fact that output price is 1
- In each sector $j = L, H$ the innovating monopolist makes an employment decision E_j , with $E_L = L$, $E_H = H$, according to:

$$\max_j \{A_{j,t} E_{j,t}^{\alpha} - w_{j,t} E_{j,t}\} = \pi_{j,t} \tag{13}$$

- market power comes from the fact that the monopolist is a **monopsonist on the labor market**
- $\pi_{j,t}$ is maximal with respect to the employment decision, $\partial\pi/\partial E = 0$.

$$w_{j,t} = \alpha A_{j,t} E_{j,t}^{\alpha-1} \tag{14}$$

$$E_{j,t} = \left(\frac{w_{j,t}}{\alpha A_{j,t}}\right)^{1/\alpha-1}$$

Remark

$$\pi_{j,t} = \max_{j}\{A_{j,t}E^{\alpha}_{j,t} - w_{j,t}E_{j,t}\} \tag{15}$$

- Because $\pi_{j,t}$ is maximal with respect to E, $\partial\pi/\partial E = 0$; we apply the envelope theorem to write:

$$\underbrace{\frac{\partial\pi_{j,t}}{\partial A_{j,t}}}_{\text{total deriv}} = \underbrace{E^{\alpha}_{j,t}}_{\text{part deriv}} + \frac{\partial\pi_{j,t}}{\partial E_{j,t}} \cdot \frac{\partial E_{j,t}}{\partial A_{j,t}} = E^{\alpha}_{j,t} \tag{16}$$

  Using the envelope condition (16)

$$\frac{\partial\pi_{j,t}}{\partial A_{j,t}} = E^{\alpha}_{j,t}$$

no arbitrage condition on the direction of R&D investments:

- In equilibrium the innovating firm is indifferent between targeting 1 extra unit of R&D investment in sector $j = H$ or $j = L$.
- The arbitrage condition states that, in equilibrium, the marginal return from R&D investment is equal in H, L

$$A_{L,t-1}\beta \cdot n_{L,t}^{\beta-1} \cdot \frac{\partial \pi_{L,t}}{\partial A_{L,t}} = A_{H,t-1}\beta \cdot n_{H,t}^{\beta-1} \cdot \frac{\partial \pi_{H,t}}{\partial A_{H,t}} \quad (17)$$

- (marginal increase in $A_{j,t}$ produced by 1 extra unit of R&D) $\times$ marginal profit increase produced by a marginal change in $A_{j,t}$
- write the no arbitrage condition as

$$A_{L,t-1} \cdot n_{L,t}^{\beta-1} \cdot L_t^{\alpha} = A_{H,t-1} \cdot n_{H,t}^{\beta-1} \cdot H_t^{\alpha}$$

- $$A_{L,t-1} \cdot n_{L,t}^{\beta-1} \cdot L_t^{\alpha} = A_{H,t-1} \cdot n_{H,t}^{\beta-1} \cdot H_t^{\alpha}$$

- Substitute for $A_{L,t-1} \cdot n_{L,t}^{\beta} = A_{L,t}$ and $A_{H,t-1} \cdot n_{H,t}^{\beta} = A_{H,t}$ from the technology of R&D (12) and (11)

$$A_{L,t} \cdot n_{L,t}^{-1} \cdot L_t^{\alpha} = A_{H,t} \cdot n_{H,t}^{-1} \cdot H_t^{\alpha}$$

- substitute from the production functions of x_L and x_H (9) , (10)

$$x_{L,t} \cdot n_{L,t}^{-1} = x_{H,t} \cdot n_{H,t}^{-1}$$

- we finally obtain:

$$\frac{x_{L,t}}{x_{H,t}} = \frac{n_{L,t}}{n_{H,t}} \tag{18}$$

Using the equilibrium wages (14), and imposing the labor market clearing conditions in the markets for skilled and unskilled labor, the skill premium is defined by

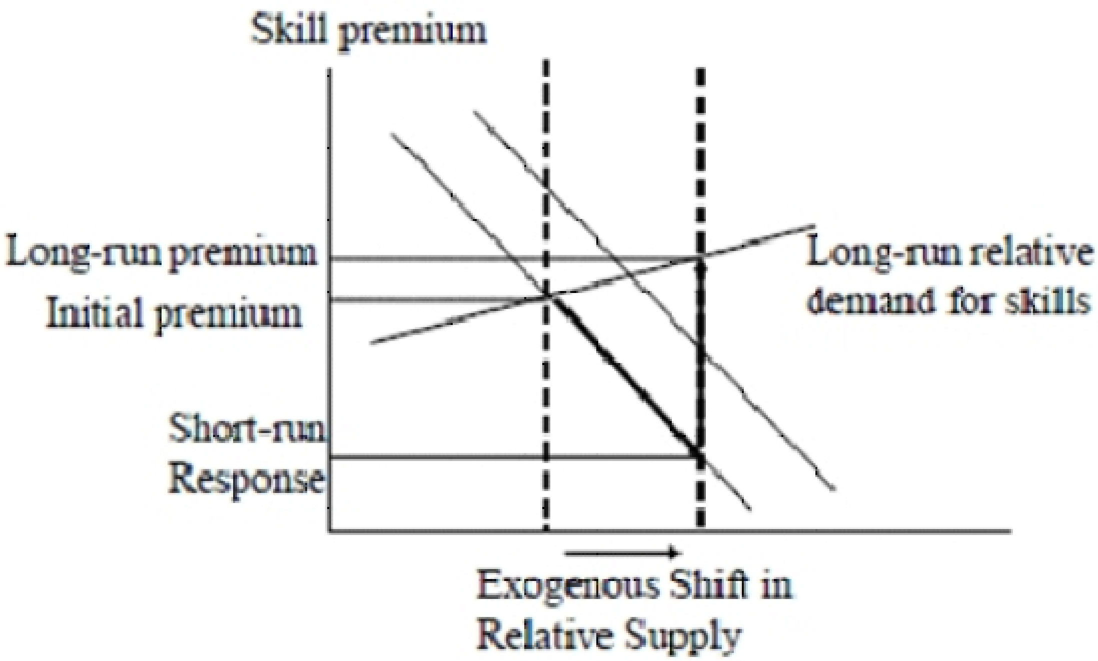
$$\varpi_t = \frac{w_{H,t}}{w_{L,t}} = \frac{A_{H,t} S_{H,t}^{\alpha-1}}{A_{L,t} S_{L,t}^{\alpha-1}} = a_t \cdot \left(\frac{S_{L,t}}{S_{H,t}} \right)^{1-\alpha} \tag{18}$$

where $1-\alpha > 0$ and $a_t = \frac{A_{H,t}}{A_{L,t}}$

Result

- At a given level of $a_t = \frac{A_{H,t}}{A_{L,t}}$, a higher relative supply of skilled labor lowers the skill premium.
- This amounts to a **short-run substitution effect**: a movement along a given short-run relative demand curve in the Figure.

  The short-run substitution effect is weaker if the parameter alpha is closer to 1 (and vice versa).



Skill premium
Long-run premium
Initial premium
Short-run
Response
Long-run relative
demand for skills
Exogenous Shift in
Relative Supply

- Recalling equations (11) and (12)

$$A_{H,t} = A_{H,t-1} n_{H,t}^{\beta}$$

$$A_{L,t} = A_{L,t-1} n_{L,t}^{\beta}$$

- we write

$$a_t = a_{t-1} \left(\frac{n_{H,t}}{n_{L,t}} \right)^{\beta}$$

- using (17)

$$a_t = a_{t-1} \left(\frac{x_{H,t}}{x_{L,t}} \right)^{\beta}$$

- using the production functions for the intermediate goods (10) and (9), we can write:

$$a_t = a_{t-1} a_t^{\beta} \left(\frac{S_{H,t}}{S_{L,t}} \right)^{\alpha\beta}$$

$$a_t^{1-\beta} = a_{t-1} \left(\frac{S_{H,t}}{S_{L,t}} \right)^{\alpha\beta}$$

$$a_t = a_{t-1}^{1/1-\beta} \left(\frac{S_{H,t}}{S_{L,t}} \right)^{\alpha\beta/1-\beta}$$

- **Acemoglu's market-size effect:**
- In the long-run relative productivity a is endogenous

$$a_t = a_{t-1}^{1/1-\beta} \left(\frac{S_{H,t}}{S_{L,t}} \right)^{\alpha\beta/1-\beta}$$

- Because $0 < \beta < 1$, a higher relative supply of skills makes R&D investment in the skill-intensive technology more attractive, because there is a wider market (market-size effect) for the skill-intensive intermediate good. This causes an increase of the relative productivity $\frac{A_H}{A_L}$.

summing up on endogenous $A_{Ht}/A_{Lt} = a_t$
short-run exogenous variables at *time t*

$$S_{Ht}, S_{Lt} \qquad A_{Ht}, A_{Lt} \to a_t$$

- short-run endogenous variables at *time t*

$$H_t, L_t \longrightarrow H/L \qquad w_{Ht}, w_{Lt} \to \omega_t \qquad x_{Ht}, x_{Lt}$$

- short-run substitution effect:

$$\frac{S_{H,t}}{S_{L,t}} \uparrow \text{ causes } \omega_t \downarrow$$

- innovation incentives depend on equilibrium employment (market-size effect):

$$\partial\pi/\partial A_H = H^\alpha \qquad \partial\pi/\partial A_L = L^\alpha$$

- marginal innovation benefits in L and H directions are equalized:

$$\frac{n_{H,t}}{n_{L,t}} \uparrow \text{ if } \frac{S_{H,t}}{S_{L,t}} \uparrow$$

$$a_t \uparrow \text{ if } \frac{S_{H,t}}{S_{L,t}} \uparrow$$

Combine the short-run subtitution effect of larger relative supply of skilled labor, with market size effect:

$$\varpi_t = a_t \cdot \left(\frac{S_{H,t}}{S_{L,t}}\right)^{\alpha-1} = a_{t-1}^{1/1-\beta} \left(\frac{S_{H,t}}{S_{L,t}}\right)^{(\alpha\beta/1-\beta)+\alpha-1}$$

Proposition 3 *An exogenous increase in the relative supply of skilled labor increases the skill premium if*

$$\frac{\alpha\beta}{1-\beta} + \alpha > 1$$

$$\frac{\alpha\beta + \alpha - \alpha\beta}{1-\beta} > 1$$

$$\alpha + \beta > 1$$

That is: the substitution effect is not too strong (α is not too low), and/or decreasing returns in R&D are not too strong (β is not too low).

4 Problems with the skill-bias explanation

4.1 USA evidence

- Poor predictions of the Goldin and Katz framework after 1992

Poor Predictions of the Goldin and Katz framework after 1992. Source Acemoglu and Autor (2012)

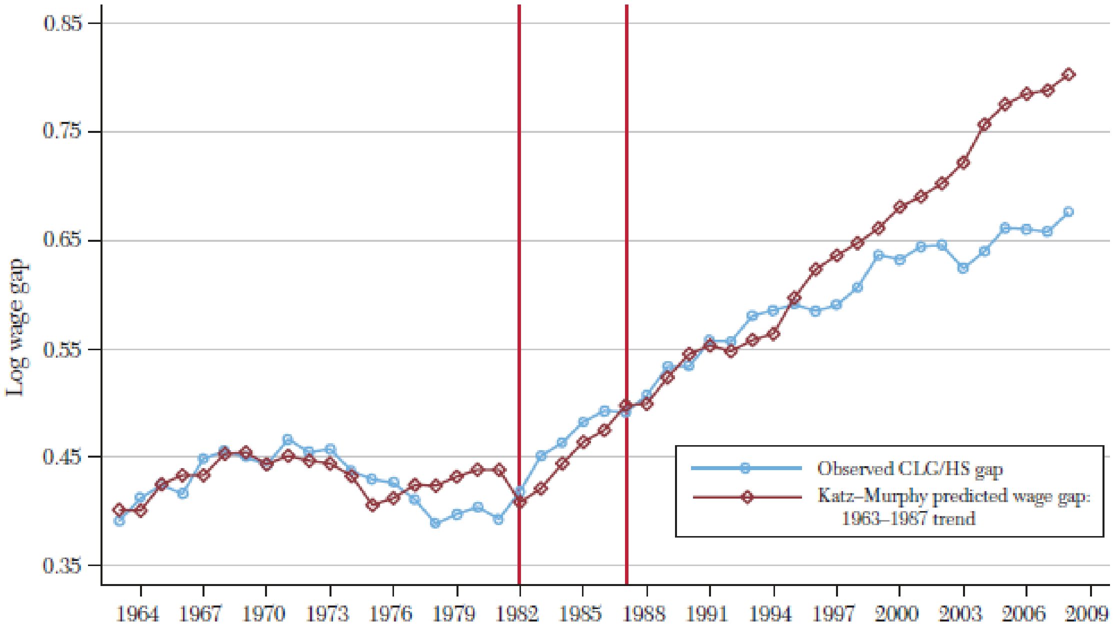
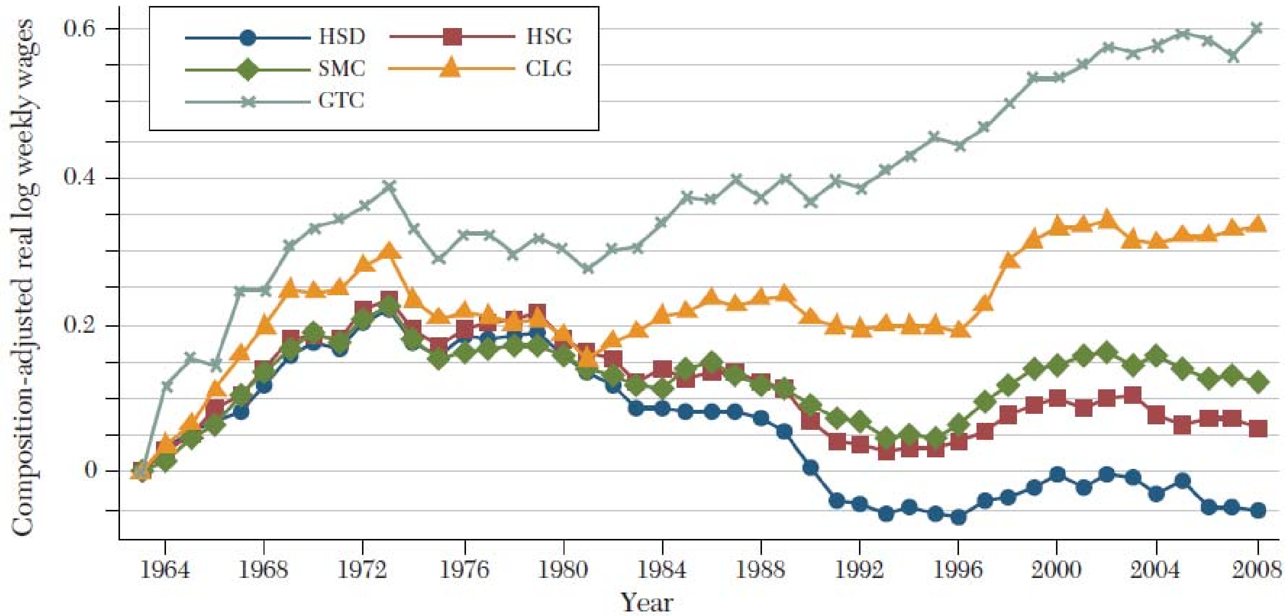


Figure 1. Katz–Murphy Prediction Model for the College–High School Wage Gap

Wage evolution by skill Source: Acemoglu, Autor (2012)



pale blu: post-college; orange: 4 years college; green: college drop-outs; brown: high-school; dark blue: high-school drop-outs.

- After 1980 increase of skill premium largely tied to: 1. fall of low-skill wage in the 1980's
  2. real wage stagnation in the middle and low range of education after 1996.
- These facts are at variance with the model predicting wage levels moving in the same direction

Change of wage by percentile of wage distribution Source: Acemoglu, Autor (2012)

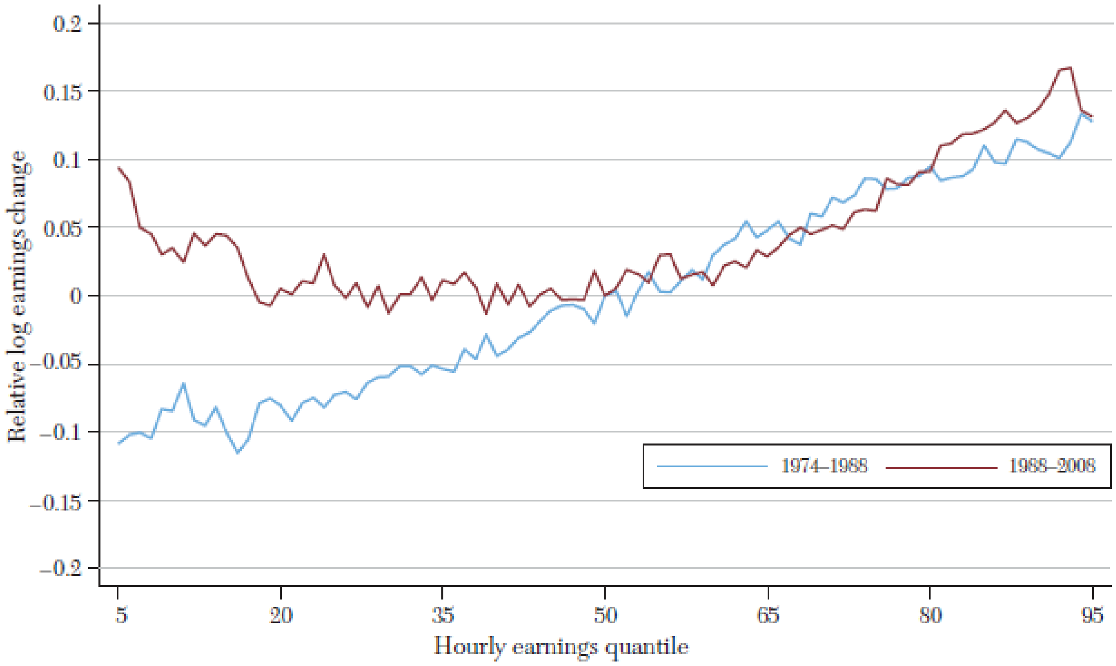


Figure 4. Changes in Male Log Hourly Wages by Percentile Relative to the Median

Source: Acemoglu, Autor (2012). **1974-1988:** Inequality increases throughout wage distribution. **1989-2009**: wage change is U shaped. High and low wages increase relative to the median wage.

Job polarization in USA after 1990. Source: Acemoglu, Autor (2012).

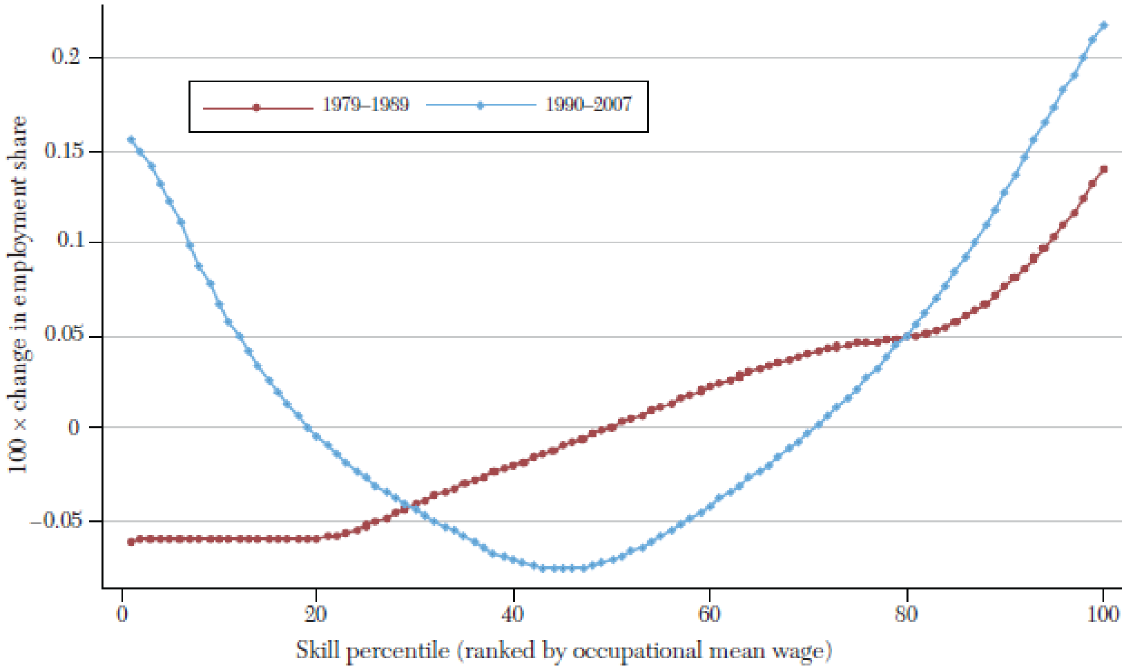


Figure 5. Smoothed Changes in Employment by Occupational Skill Percentile, 1979–2007

Low and high skill 'tasks' increase their employment share after 1990

wage-setting institutions: minimum wage Source: Lemieux (2008)

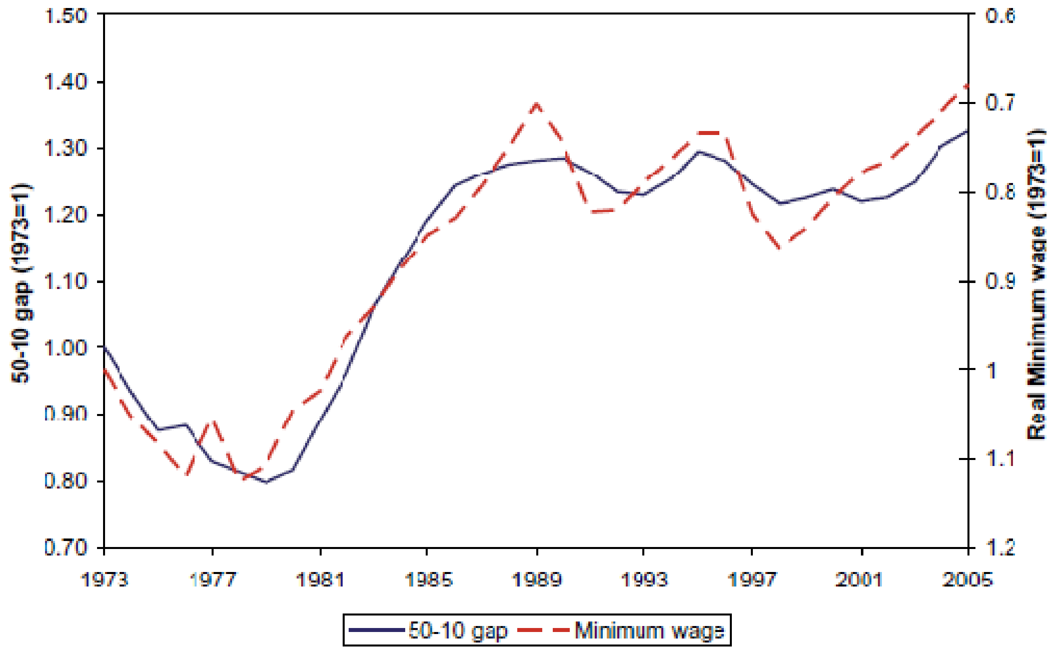


Fig. 5 50–10 gap for women vs minimum wage

50-10 percentile gap of female wage (Left scale); evolution of minimum wage (Right scale)

Most of the change in minimum wage takes place in the pre-1986 period. This is the period in which the Goldin-Katz model performs quite well 'in the aggregate'.

wage-setting institutions: de-unionization Source: Lemieux (2008)

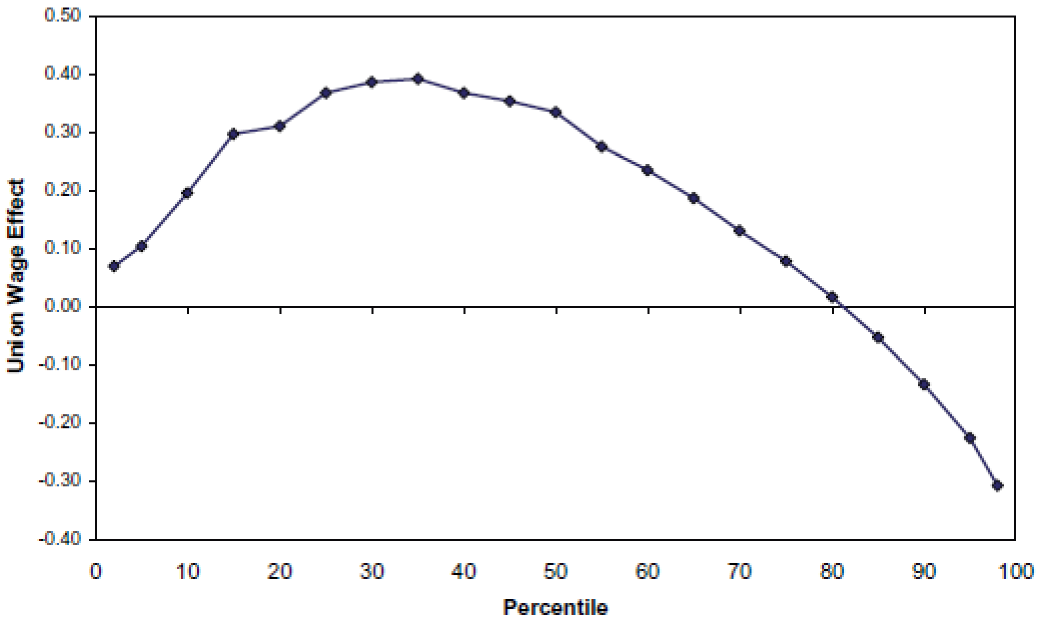


Fig. 6 Union effect by wage percentile, men

Wage effect of unions strongest for middle-range wages, weakest for high wages.

Changes in wage setting institutions: performance pay

- growing diffusion of performance pay in wage contracts
- workers on performance pay tend to be more educated and to work in better paid occupations, then workers not paid for performance.

4.2 International evidence

- **Skill-biased technical change is expected to be ubiquitous in advanced countries, but the rise in the skill premium is not.**
- Rise in skill premium much stronger in USA and UK than in France and Germany (Piketty and Saez 2006)
- In Italy educational wage premia **fall in the private sector** between 1993 and 2004 (Naticchioni et al 2011)
- **wage polarization and job polarization after 1990 is common to USA and Europe** (Goos, Manning, Salomons 2009, 2014)

Other authors argue that there are important differences between USA and Europe and within Europe.

5 Acemoglu and Autor (2010) model of tasks and skills

Four factors of production:

- K = Supply of physical capital
- L = supply of low-skill labor
- M = supply of medium skill labor
- H = supply of high skill labor

Final output Y is a CES aggregate of a continuum of tasks

$$Y = \left[\int_0^1 y(i)^\rho \partial i \right]^{1/\rho}$$

$$\rho = \frac{\eta - 1}{\eta}$$

$\eta = \frac{1}{1-\rho} = |\text{elasticity of substitution between tasks}|$

Assume the Cobb-Douglas case $\eta = 1$, $\rho = 0 A_{Ht}, A_{Lt} \rightarrow a_t$

$$\ln Y = \int_0^1 \ln y(i) \partial i$$

factors K,L,M,H are perfect substitutes in the production of task-specific output $y(i)$

$$y(i) = A_L \alpha_L(i) l(i) + A_M \alpha_M(i) m(i) + A_H \alpha_H(i) h(i) + A_K \alpha_K(i) k(i)$$

$A_Z =$ task generic factor augmenting technological coefficient, $Z \in \{L, M, H, K\}$
$\alpha_Z(i) =$ task specific technological coefficient, $Z \in \{L, M, H, K\}$

- Assume temporarily that no physical capital is used in production $\alpha_K(i) = 0$, $i \in [0, 1]$
- Sructure of comparative advantage between L, M and H

$$\frac{\alpha_L(i)}{\alpha_M(i)} \text{ and } \frac{\alpha_M(i)}{\alpha_H(i)}$$

are strictly decreasing with respect to i. Higher indices i correspond to 'more complex' tasks

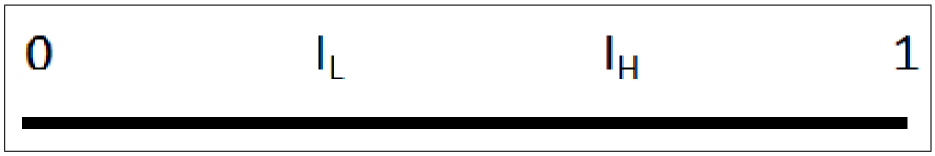
- Factor market clearing

$$\int_0^1 \ln l(i)\partial i \leq L \qquad \int_0^1 \ln m(i)\partial i \leq M \qquad \int_0^1 \ln h(i)\partial i \leq H \tag{19}$$

- with strict equality if $w_L > 0$, $w_M > 0$, $w_H > 0$.

In equilibrium:

- the task continuum $[0, 1]$ is partitioned into three factor-specific sets of tasks: $[0, I_L]$; $[I_L, I_H]$; $[I_H, 1]$



- low skill labor L is used in the production of $y(i)$ only if $i \in [0, I_L]$
- medium skill labor M is used in the production of $y(i)$ only if $i \in [I_L, I_H]$
- high skill labor H is used in the production of $y(i)$ only if $i \in [I_H, 1]$
- no arbitrage condition: it is indifferent producing $y(I_L)$ with low or medium skill labor
- no arbitrage condition: it is indifferent producing $y(I_H)$ with medium or high skill labor
- the other 'interior tasks' $i \in [0, 1]$ are covered by one type of labor only

5.1 Task generic factor-augmenting increase in A_H

- higher productivity of high-skill workers
- some of the tasks previously performed by medium skill workers are shifted to high skill workers: I_H is shifted to the left
- a corresponding shift of low skill tasks $i \in [0, I_L]$ to medium skill workers may not be profitable: I_L is unchanged

- **The higher A_H may cause a lower equilibrium wage w_M of medium skill workers**

5.2 Task specific technological change

- A intermediate range of tasks $[I', I''] \subset [I_L, I_H]$ consists of routine tasks that are most subject to machine-displacement through autamation
- If $i \in [I', I'']$, then $\alpha_K(i) > 0$
- If $i \notin [I', I'']$, then $\alpha_K(i) = 0$ as before
- Because physical capital K and the three types of labor are perfect substitutes in the production of task-specific output $y(i)$, if $\alpha_K(i)$ is sufficiently large for $i \in [I', I'']$, medium skill workers are displaced by machines in this range of tasks.
- In equilibrium, the displaced workers are employed in tasks for which they have a lower comparative advantage, causing a fall of the equilibrium wage w_M
- The lower cost of producing output from the automated tasks (the cost of producing $y(i)$ falls, if for $i \in [I', I'']$) causes greater intensity of use of these tasks $i \in [I', I'']$ in the production of aggregate output Y, and a corresponding increase of the marginal product of low skill and high skill labor: w_L and w_H rise accordingly.

The skill and task models explains:

- wage polarization: fall of medium skill wage w_M relative to the wages w_L, w_H of low-skill and high-skill workers
- job polarization: employment polarization in low-skill and high-skill tasks, relative to employment in middle-skill tasks
- The supply of L, M, H are exogenous and fixed

Extensions:

- Endogenous factor supply of L, M, H, through migration, human capital accumulation, changes in wage distribution
- Demand-side explanations of employment polarization. Example: productivity growth causes a substitution of market activities for non-market activities (home production) in the supply of personal services, that have a high income elasticity of demand. Low skill workers L have a comparative advantage in the production of personal services.

H. Fernandez Macias (2012) “Job polarization in Europe?”

Employment change by wage quintiles in Europe 1995-2007

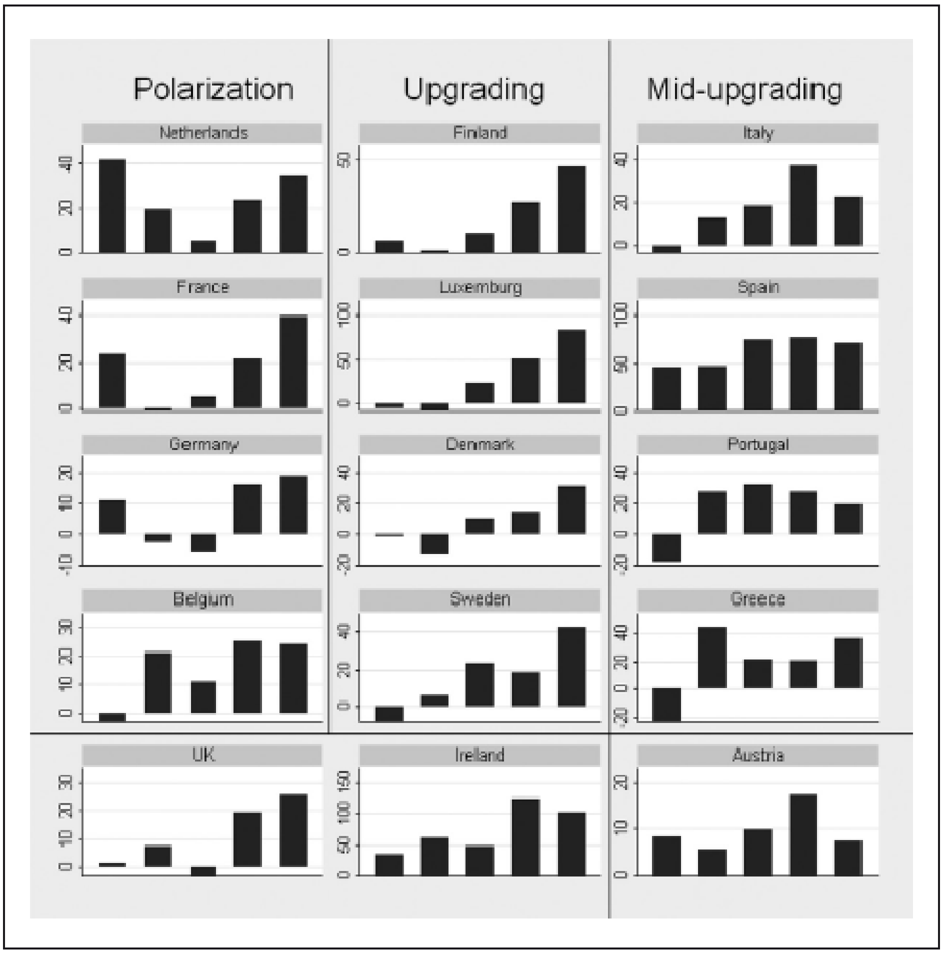


Figure 1. Relative change in employment by wage quintiles, 1995-2007

if task complexity is approximated by pay, polarization conforms to relative loss of jobs in middle tasks

Upgrading: relative employment change correlated with task-complexity

Mid-upgrading: employment performs better in industries in which middle tasks are more frequent

Employment change by education quintiles in Europe 1995-2007

if task complexity is approximated by education, polarization conforms to relative loss of jobs in middle tasks

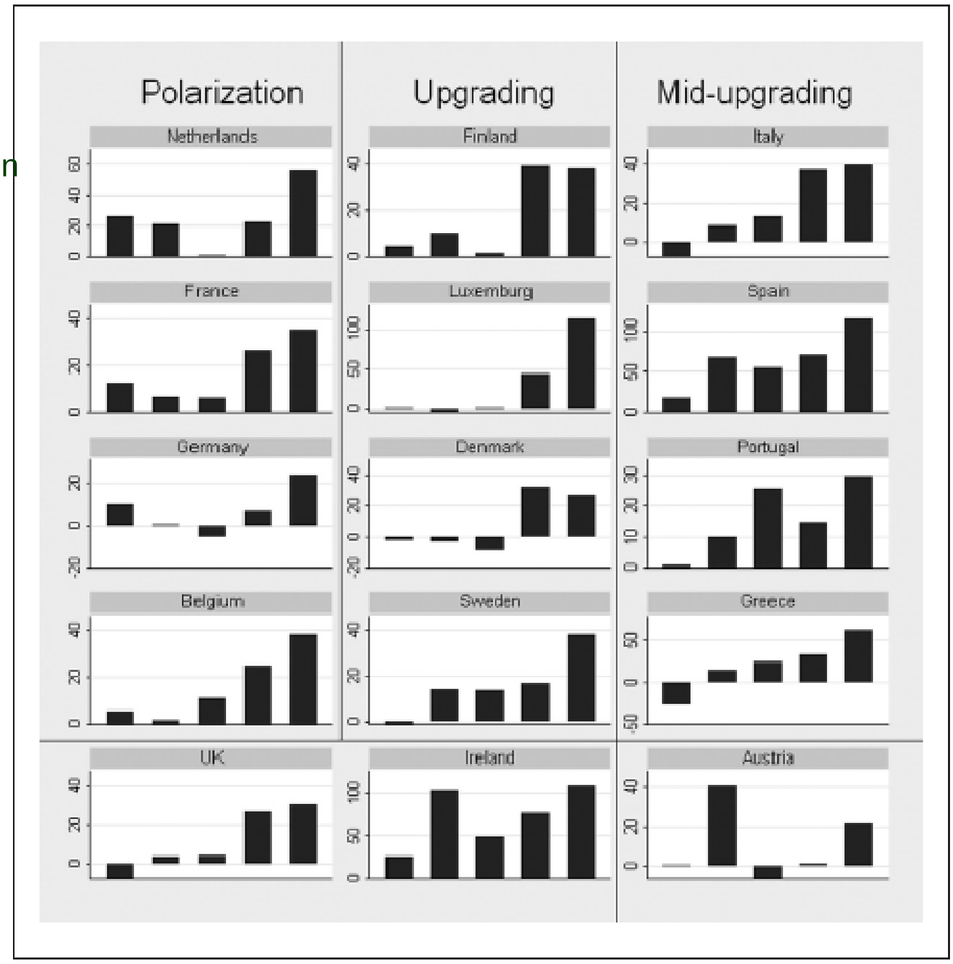


Figure 2. Relative change in employment by education quintiles, 1995-2007

Remark

- Notice that the countries in the 3rd mid-upgrading group of Macias (2012), where job-polarization does not prevail, are mainly South-European countries
- One may then conjecture that job-polarization does not prevail in this countries simply because they are still late in the introduction of robots
- As it turns out, *this hypothesis is contradicted by evidence* in Graetz and Michaels (2018), showing, for instance, that Italy is a leader in robot densification in 1993-2007

FIGURE 1.—THE PRICE OF ROBOTS IN SIX COUNTRIES, 1990–2005

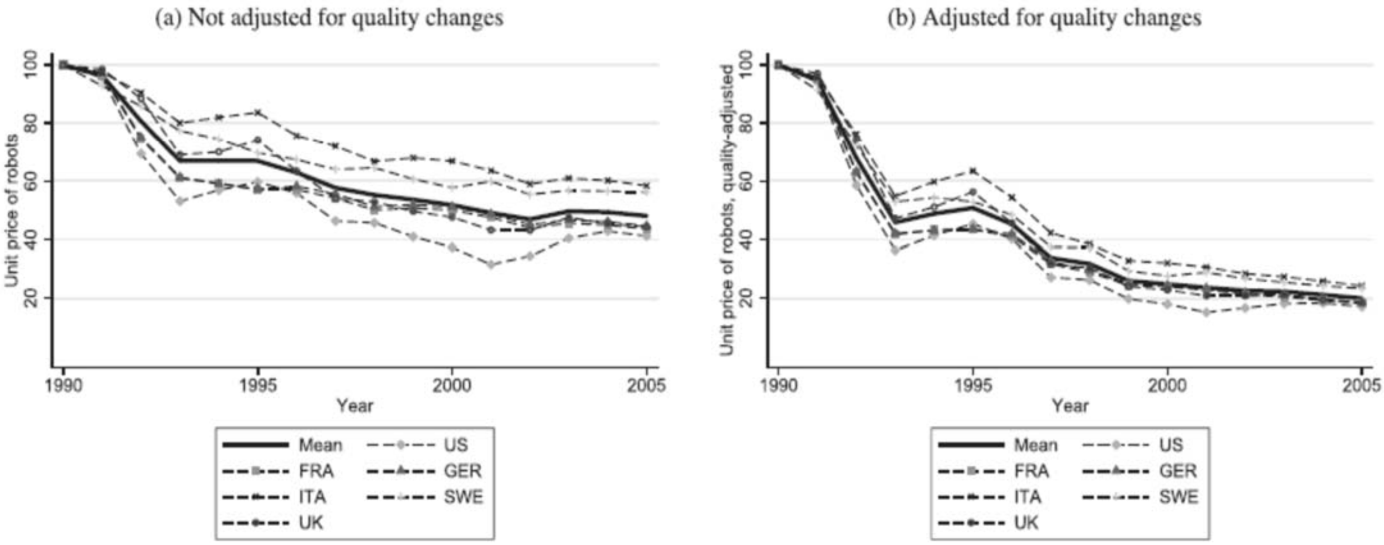
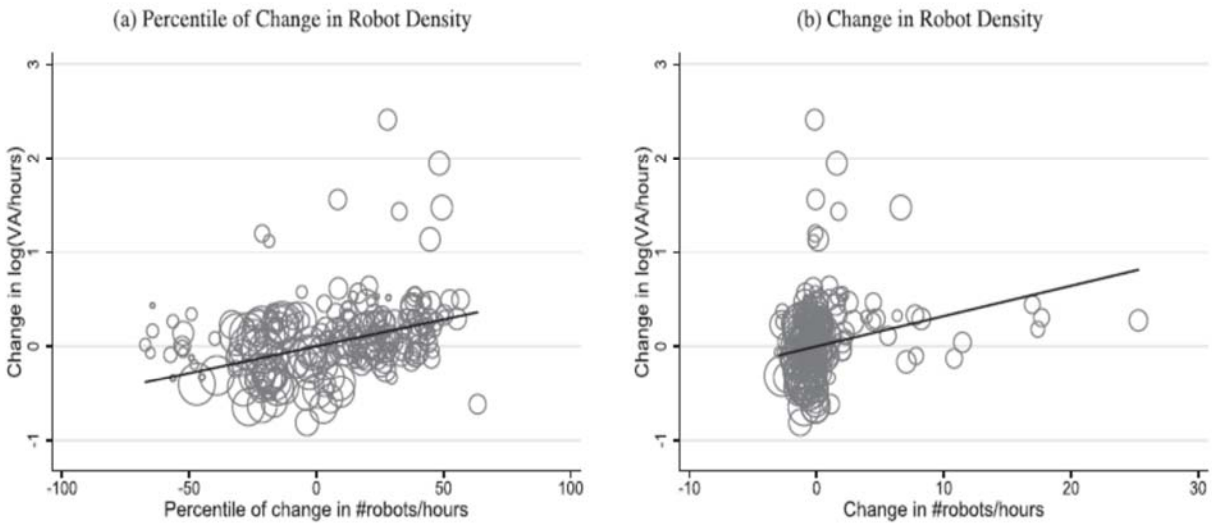


Figure in Graetz and Michaels (2018), data source: International Federation of Robotics (2006)

FIGURE 2.—GROWTH OF PRODUCTIVITY AND ROBOTS, 1993–2007



Observations are country-industry cells. The size of each circle corresponds to each industry's 1993 within-country employment share. Fitted regression lines are shown. Measures of robot adoption are net of country trends. (a) The estimated slope is 0.57 with a robust standard error (two-way clustered by country and industry) of 0.27. (b) The estimated slope is 0.032, and the standard error is 0.016.

Figure in Graetz and Michaels (2018). Data source for robot density: International Federation of Robotics (2012), EUKLEMS (Timmer et al. 2007). Robot density: stock of robots per million hours worked

robot density and productivity growth (Graetz and Michaels 2018)

14 industries, 17 countries: 14 x 17 industry-country pairs

- On average in 1993-2007 robot density increases by 150%
- Maximum increase in Germany, Denmark and Italy
- (percentage) change in robot density **positively and significantly correlated with productivity growth**
- in 1993-2007 in the 17 countries, robot intensification contributes to average country-level annual productivity growth of 2.4% by an 0.36% per year
- **similar to the contribution of steam technology** to British annual labour productivity growth estimated by Crafts (2004) at 0.35%
- Marginal contribution of robot density to productivity growth is decreasing
- US evidence is different (Acemoglu et al. 2014): IT effects on US productivity growth are concentrated in **IT-producing industries**, not **IT-using industries**.

robot density, skill-bias and distribution

- In the industry-country pairs examined by Graetz and Michaels (2018) robot densification has:
- No significant effects on the *labour share* in income
- Positive effects on *wage and TFP* levels
- No significant negative effect on *industry employment* (unlike Acemoglu and Restrepo 2017, based on US evidence)
- Significant negative effect on employment of *low-skill workers*, rather than medium-skill workers
- According to Graetz and Michaels (2018) automation is *skill-biased*, but not in the direction described by the Acemoglu-Autor (2011) model.

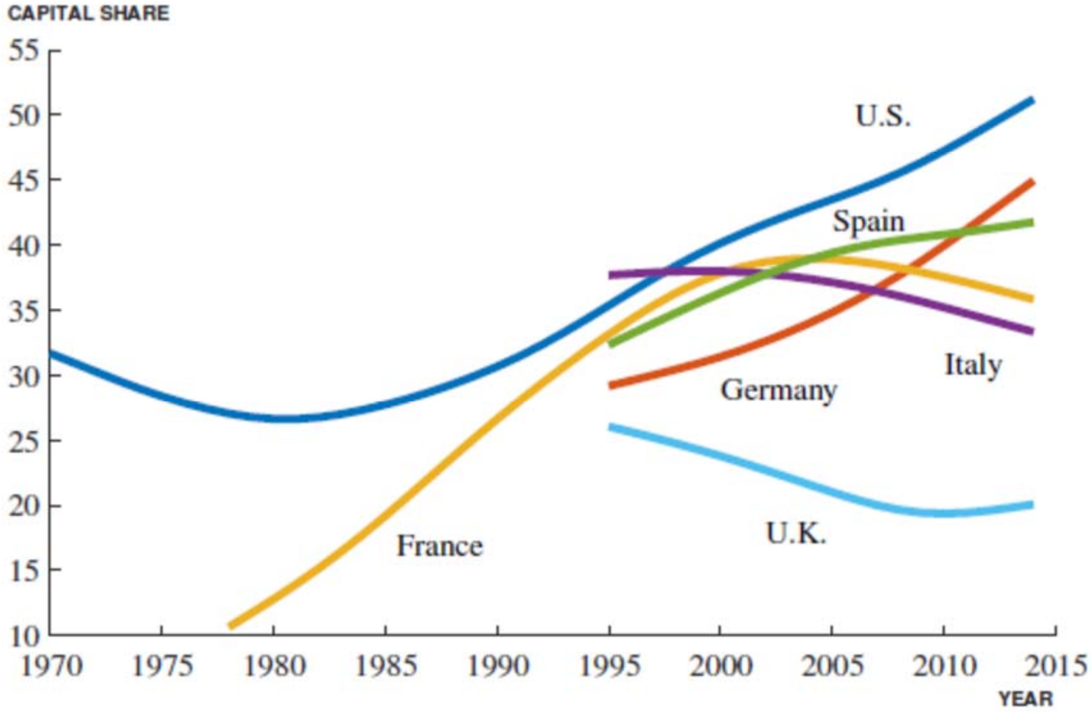
  question: are the low-skill workers in the automating industries positioned in the low range of the AGGREGATE skill distribution?

Puzzles in search of solution

- US evidence on the effects of automation partly differs from the evidence in other developed countries
- Concerning the international evidence of job-polarization (Goos, Manning, Solomons 2014): How far is it explained by off-shoring, and how far by automation?
- What is the skill-bias of robot technology and how does it compare with the skill-bias of IT technology in general?
- It is a fact that since the advent and diffusion of IT technology in the 1980s, there has been a downward movement of the wage share in many advanced countries. Still, there is no evidence that this change in distribution can be explained by robot technology at the industry level. But workers relaced by robots may find a job in other industries, possibly at a lower wage.

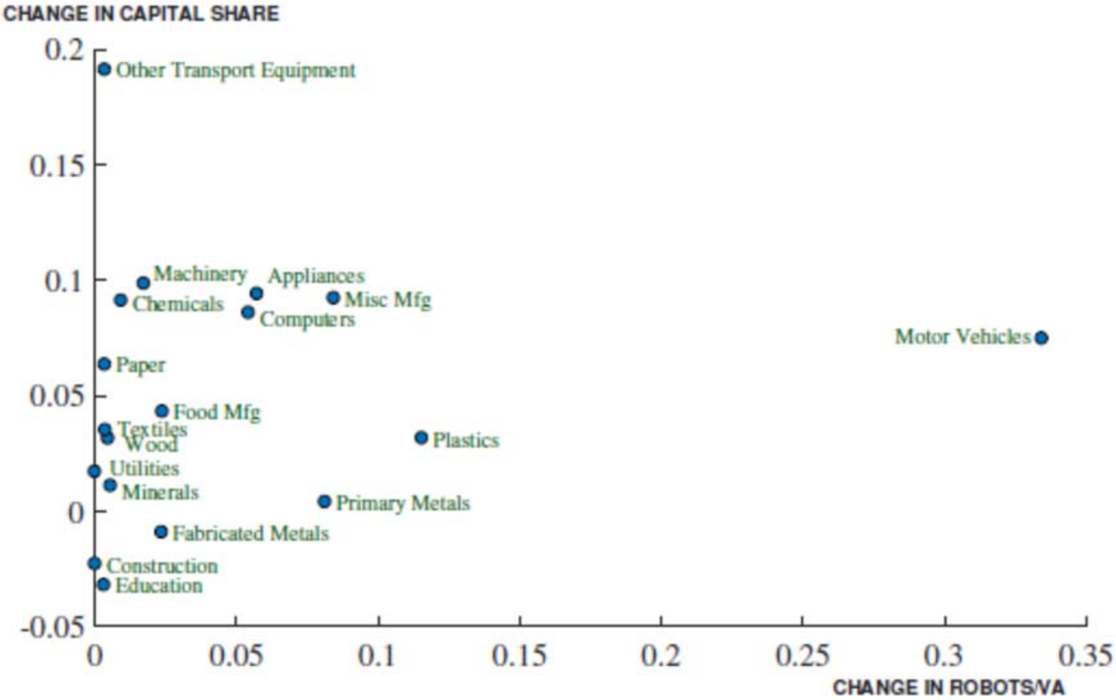
  Absence of significant correlation between robots introduction and the wage share at industry level does not imply that there is no correlation in the aggregate...

Figure 7: The Capital Share for Transportation Equipment



Note: Data for the European countries are from the EU-KLEMS project at http://www.euklems.net/ for the "transportation equipment" sector, which includes motor vehicles, but also aerospace and shipbuilding; see Jägger (2016). U.S. data are from Jorgenson, Ho and Samuels (2017) for motor vehicles. Shares are smoothed using an HP filter with smoothing parameter 400.

Figure 8: Capital Shares and Robots, 2004–2014



Note: The graph plots the change in the capital share from Jorgenson, Ho and Samuels (2017) against the change in the stock of robots relative to value-added using the robots data from Acemoglu and Restrepo (2017).