MIT 14.662 Spring 2018: Lecture 4 – Skills, Tasks, and Technologies

David Autor, MIT and NBER

February 20, 2018

Agenda

1. **Motivation: The Canonical Model**
   - Wage inequality rises less than predicted
   - Falling real wage levels for some groups
   - Convexification of returns to education
   - ‘Polarization’ of employment across advanced economies
   - Wage polarization
   - Declining labor share
2. **A Task Model**
   - Model setup
   - The displacement effect—Extensive margin tech Δ
   - Productivity effect
   - Deepening of automation—Intensive margin tech Δ
   - Capital accumulation
   - New task creation
3. **Full Blown Acemoglu-Autor Task Model**

The Canonical Model

Elegantly, powerfully operationalizes supply and demand for skills

- A formalization of Tinbergen's "Education Race" analogy
- Two distinct skill groups that perform two different and imperfectly substitutable tasks

Model is a theoretical and empirical success

- Katz and Murphy '92
- Card and Lemieux '01
- Acemolgu, Autor and Lyle '04
- Goldin and Katz '08
- Carneiro and Lee '11

But its limitations are also increasingly apparent

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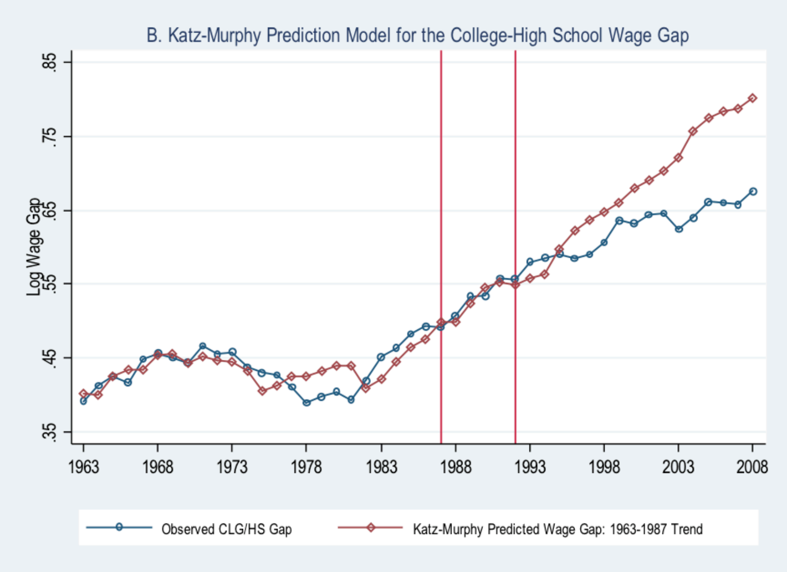
Wage Inequality Rises Less than Predicted by the Canonical Model



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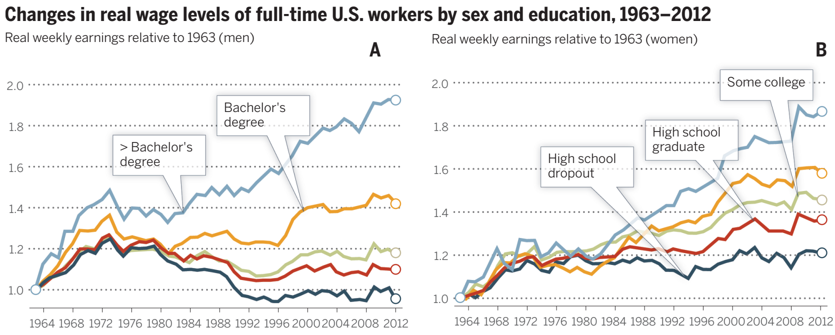
Declining Real Wages for Non-College Workers – Despite Falling Relative Supply



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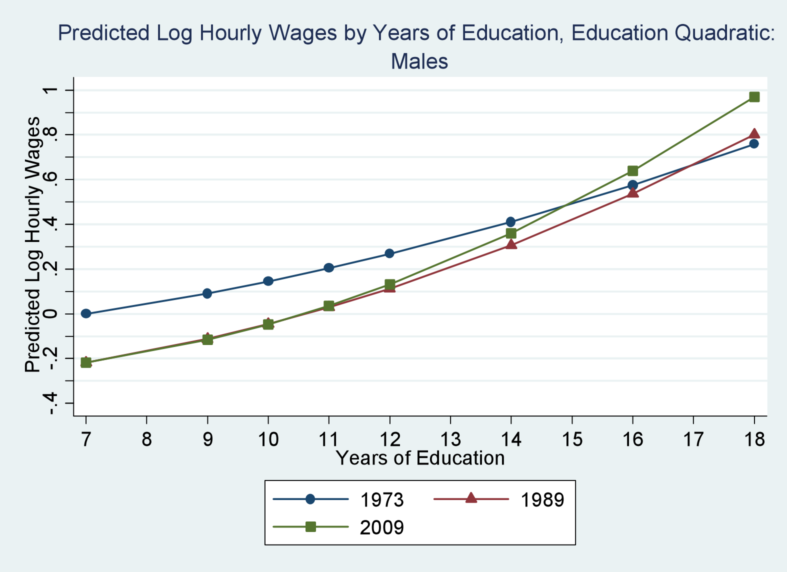
‘Convexification’ of the Return to Education



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Occupational Polarization, 1979 – 2010 Percent Growth in Employment by Occupation

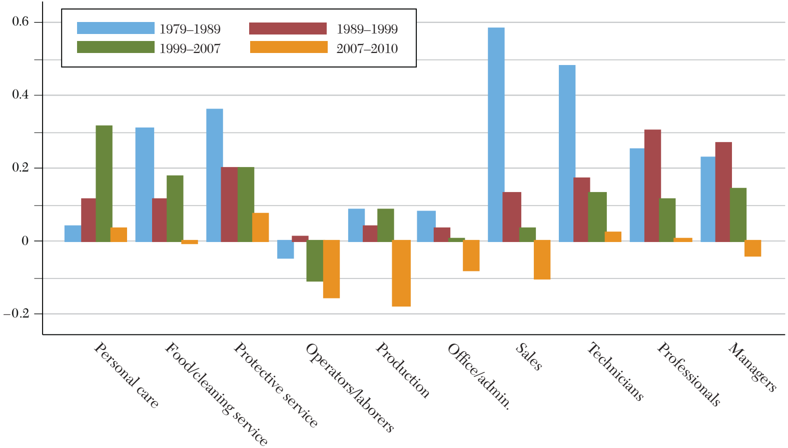
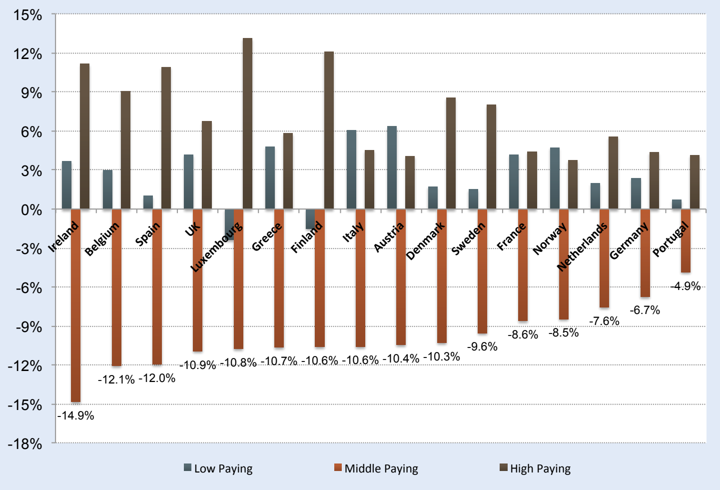


Figure 6. Percent Change in Employment by Occupation, 1979–2010

Occupational Polarization in Sixteen European Union Countries, 1993 - 2010



Goos, Manning and Salomons, 2014

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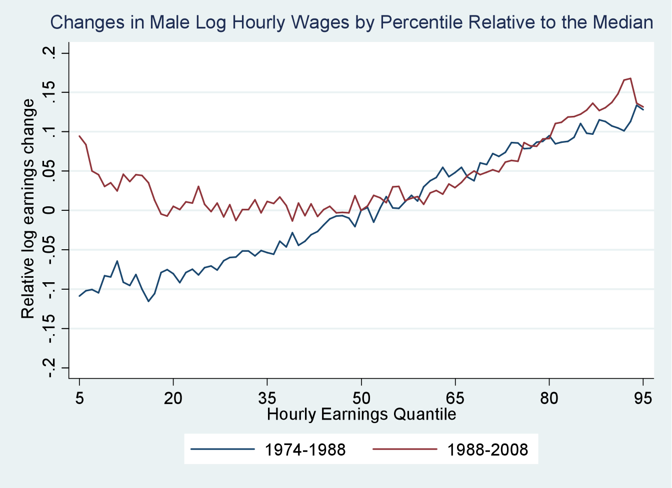
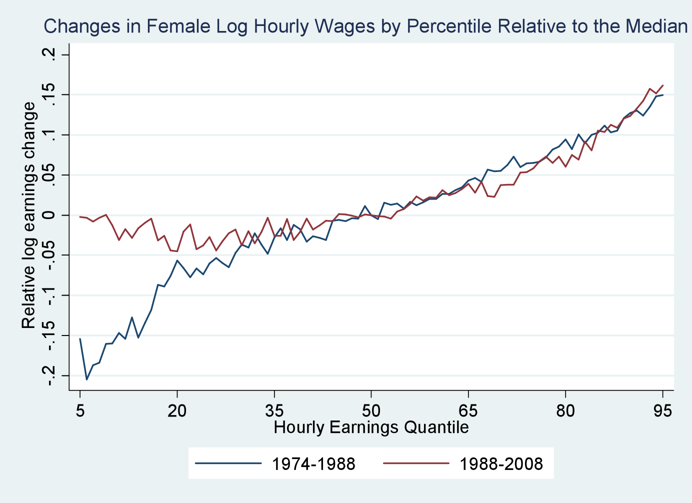
Wage Polarization: Males



Acemoglu and Autor 2011

Wage Polarization: Females



Acemoglu and Autor 2011

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Labor's Falling Share of National Income

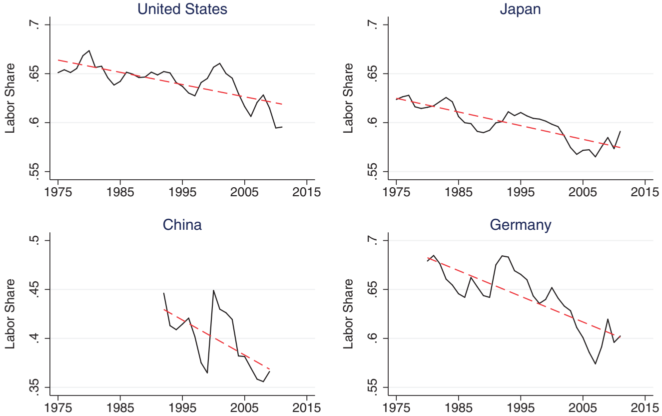


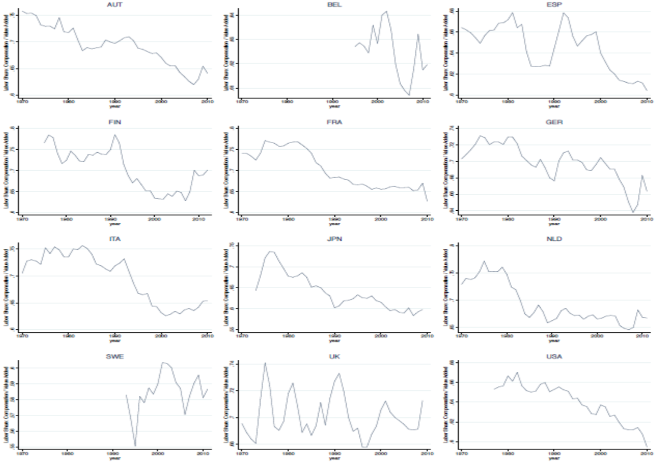
FIGURE II

Declining Labor Share for the Largest Countries

Karabarbounis and Neiman, 2014

Labor's Falling Share of National Income

Figure 1: International Comparison: Labor Share by Country



Notes: Each panel plots the ratio of aggregate compensation over value-added for all industries in a country based on KLEMS data.

Autor, Dorn, Katz, Patterson, & Van Reenen 2017

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A model of tasks and technologies

1. **Explicit distinction between skills and tasks**
   - Tasks—Unit of work activity that produces output
   - Skill—Worker's endowment of capabilities for performing various tasks
2. **Allow for comparative advantage among workers and machines in accomplishing tasks**
   - Assignment of workers to tasks is *endogenous* (as in Roy, 1951)
3. **Allow for multiple sources of competing task 'supplies'**
   - Workers of different skill levels
   - Machines—Task can be routinized/automated
   - Trade/offshoring—Tasks can be performed elsewhere
4. **Trade and automation**
   - Substitution of machines or foreign workers for labor, lead to the displacement of workers from some tasks

Task Framework: Motivation

Framework builds on

- Zeira (1998)
- Autor, Levy, Murnane (2003)
- Grossman, Rossi-Hansberg (2008)
- Acemoglu and Autor (2011)
- Acemoglu and Restrepo (2016, 2017, 2018a - 2018z^3)

1. First model in this lecture: **Acemoglu and Restrepo (2017)**, "Artificial Intelligence, Automation, and Work"
2. Second model in this lecture: **Acemoglu-Autor** (2011), "Skills, Task and Technologies" (AKA the Handbook Chapter or HoLE)

Task Framework: Historical Context

Production requires the completion of a range of tasks

- In **textiles**, looms and weaving machines replaced manual spinning and knitting
- **Machine tools**, such as lathes and milling machines, replaced labor-intensive production techniques relying on skilled artisans
- In **agriculture**, horse-powered reapers, harvesters, and threshing machines replaced manual labor working with rudimentary tools
- **Robotics**, **software** and current practice in **AI** continue this trend of using machines and computers to automate labor intensive tasks
- Applies equally to **importing intermediate inputs** or to **'offshoring'** a set of tasks

Key idea—tasks are complements

- Automating a subset does not make the remainder redundant
- Extreme example: O-Ring Production Function (Kremer '93)

Space Shuttle Challenger Liftoff — 28 January 1986

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Task Framework: Model

Aggregate output Y

- Produced by combining the services, $y(x)$, of a unit measure of tasks $x \in [N-1, N]$:

$$\ln Y = \int_{N-1}^{N} \ln y(x) dx, \tag{1}$$

- Tasks run between $N-1$ and N allows for changes in *range* of tasks
- Notice that this is a Cobb-Douglas structure with identical factor shares for services of each task

Task Framework: Model

Tasks produced by human labor, $\ell(x)$, <u>or</u> by machines, $m(x)$

- Tasks above I are **not technologically automated** and must be produced by labor:

$$y(x) = \begin{cases} \gamma_L(x)\ell(x) + \gamma_M(x)m(x) & \text{if } x \in [N-1, I] \\ \gamma_L(x)\ell(x) & \text{if } x \in (I, N]. \end{cases} \quad (2)$$

- $\gamma_L(x)$ =productivity of labor in task x, increasing in x
- $\gamma_M(x)$ =productivity of machines in automated tasks
- **Comparative advantage**: $\gamma_L(x)/\gamma_M(x)$ is increasing in x
- L workers and K units of capital (machines) supplied inelastically

Task Framework: Aggregate Output

Simplifying assumption

$$\frac{\gamma_L(N)}{\gamma_M(N-1)} > \frac{W}{R} > \frac{\gamma_L(I)}{\gamma_M(I)} \tag{A1}$$

- where R is the capital rental rate
- Implies that tasks below I are produced with machines/offshoring

Assumption says that new tasks (rising N) raise output

- Wage ratio not so high that new task creation lowers output
- Not so low so that technologically automated tasks are still performed by labor

Task Framework: Aggregate Output

Aggregate output takes the form

$$Y = B\left(\frac{K}{I-N+1}\right)^{I-N+1}\left(\frac{L}{N-I}\right)^{N-I},$$
$$B = \exp\left(\int_{N-1}^{I}\ln\gamma_M(x)dx + \int_{I}^{N}\ln\gamma_L(x)dx\right)$$

- Notice that this production function is **pure Cobb-Douglas with non-constant shares**
- B = Solow residual: *All* technological Δ generates Hicks-neutral TFP gain ΔB

Task Framework: The Demand for Labor

The demand for labor is given by

$$W = (N - I)\frac{Y}{L} \tag{3}$$

- This expression is equal to labor share of total output, $(N - I)$, times output Y divided by number of workers L
- The share of labor in national income is given by

$$s_L = \frac{WL}{Y} = N - I \tag{4}$$

Task Framework: Four Forces at Play

1. **Labor-augmenting technological advances**
   - Increases in the function $\gamma_L(x)$
   - This is the canonical factor-augmenting model
2. **Automation at the extensive margin – displacement**
   - Expansion of the set of tasks that are technologically automated or trade-substituted, I
   - Not present in conventional models
3. **Automation at the intensive margin – deepening of automation**
   - Increases in the productivity of tasks that are already automated/offshored.
   - Corresponds to an increase in the $\gamma_M(x)$ function for tasks $x < I$
4. **Creation of new tasks**
   - An increase in N
   - (a new idea due to Acemoglu-Restrepo '16)

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The Displacement Effect — Extensive margin tech Δ

Automation or trade/offshoring (an increase in I) generates a displacement effect

- From equation (3)

$$\frac{d\ln W}{dI} = \underbrace{\frac{d\ln(N-I)}{dI}}_{\substack{\text{Displacement} \\ \text{effect} < 0}} + \underbrace{\frac{d\ln(Y/L)}{dI}}_{\substack{\text{Productivity} \\ \text{effect} > 0}} . \tag{5}$$

- The displacement effect implies that **wages—marginal product of labor—can decline**, despite the fact that output per worker rises
- **Wages necessarily grow by less than output per worker** $\rightarrow$ labor share falls

$$\frac{ds_L}{dI} = -1 < 0 \tag{6}$$

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Countervailing Force 1. The Productivity Effect

By reducing the cost of producing a subset of tasks, automation/trade raises the demand for labor in remaining tasks

- Formally

$$\frac{d\ln(Y/L)}{dI} = \ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right) > 0$$

- Note that $\ln\left[w/\gamma_L\left(I\right)\right] - \ln\left[R/\gamma_M\left(I\right)\right]$ is the cost difference btwn labor and capital/offshoring in the marginal task I
- The overall impact on labor demand can be written as

$$\frac{d\ln W}{dI} = \underbrace{-\frac{1}{N-I}}_{\substack{\text{Displacement}\\ \text{effect} < 0}} + \underbrace{\ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right)}_{\substack{\text{Productivity}\\ \text{effect} > 0}}. \tag{7}$$

Countervailing Forces 1. The Productivity Effect

The overall impact on labor demand can be written as

$$\frac{d\ln W}{dI} = \underbrace{-\frac{1}{N-I}}_{\substack{\text{Displacement} \\ \text{effect} < 0}} + \underbrace{\ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right)}_{\substack{\text{Productivity} \\ \text{effect} > 0}}. \quad (8)$$

1. **Case 1: Productivity effect dominates displacement effect**: $\gamma_M(I)/R >> \gamma_L(I)/W$. Productivity jump big enough to overcome displacement effect
2. **Case 1: Displacement effect dominates productivity effect**: $\gamma_M(I)/R \approx \gamma_L(I)/W$. New technologies/trade are so-so

Countervailing Force 1. The Productivity Effect

Two complementary manifestations of the productivity effect

1. **Raising labor demand in non-automated tasks in adopting sectors**
   - **Uber effect:** People take a lot more 'cab rides' than they used to
   - ATMs raised demand for tellers (Bensen, 2016)
   - Automation in weaving increased the price of yarn and the demand for the complementary task of spinning (Mantoux, 1928)
2. **Raising demand for labor in other industries**
   - **Costco effect**: Raises labor demand in customer sectors
   - **Walmart effect:** Walmart raises household purchasing power, increasing spending elsewhere
   - By reducing food prices, mechanization enriched consumers who then demanded more non-agricultural goods (Herrendorf, Rogerson and Valentinyi, 2013)

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Countervailing Force 2. Deepening of automation – Intensive margin tech Δ

Initially, a task or process is automated/offshored $\rightarrow$ Displacement

- Subsequent improvements or cost reductions in already-automated tasks may raise productivity without further displacement
- Consider an increase in the productivity of machines by $d \ln \gamma_M(x) = d \ln \gamma_M > 0$ for $x < I$, with no change in the extensive margin of automation, I
- Wage impact is

$$d \ln W = d \ln Y/L = (I - N + 1) d \ln \gamma_M > 0$$

- Intensive margin improvements tend to increase labor demand and wages, further counteracting the displacement effect
- This is a pure capital-skill complementarity

Countervailing Force 2. Intensive margin: Some examples

- Improvements in tractors make farm workers more efficient without changing task allocation
- Faster broadband speeds allow profs to do better online classes
- Better auto-assembly robots improve the quality of welds on new cars (even though robots have been doing the welding for years)

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Countervailing Force 3. Capital Accumulation

If capital supply fixed, displacement effect on W magnified

- **With fixed supply of capital**
  - Automation at extensive margin increases the demand for capital
  - Raises the equilibrium rental rate, R
- **"Medium-run"**
  - Supply of machines expands as well (or more offshore supplies come online)
  - Capital accumulation bolsters the productivity effect by reducing the cost of machinery
  - If capital accumulation fixes R, productivity effect dominates the displacement effect—**all gains go to inelastically supplied factor**

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Countervailing Force 4. New Tasks

Creation of new, labor-using tasks may be counterbalancing force

1. In 19th-century Britain, rapid expansion of new industries and jobs—engineers, machinists, repairmen, and managers (Landes, 1969, Chandler, 1977, and Mokyr, 1990)
2. In early 20th-century America, agricultural mechanization coincided with a large increase in employment in new industry and factory jobs (Olmstead and Rhode, 2001, Rasmussen, 1982)
3. From 1980 to 2010, new tasks and job titles explain non-negligible share of employment growth (Acemoglu and Restrepo, 2016)
4. In general, new tasks tend to be more skill-intensive—which is both good and bad news

New Tasks and the Demand for Labor

- **An increase in N—the creation of new tasks—raises productivity**

$$\frac{d \ln Y/L}{dN} = \ln\left(\frac{R}{\gamma_M(N-1)}\right) - \ln\left(\frac{W}{\gamma_L(N)}\right) > 0$$

  which is positive from Assumption A1

- Besides its effect on productivity, new tasks also increase labor demand and equilibrium wages by creating a *reinstatement effect*:

$$\frac{d \ln W}{dN} = \underbrace{\ln\left(\frac{R}{\gamma_M(N-1)}\right) - \ln\left(\frac{W}{\gamma_L(N)}\right)}_{\substack{\text{Productivity} \\ \text{effect} > 0}} + \underbrace{\frac{1}{N-I}}_{\substack{\text{Reinstatement} \\ \text{effect} > 0}} \tag{9}$$

- (Reinstatement effect partially an artifact of unit range of tasks)

New Tasks and Automation

Creation of new tasks generates additional labor demand, increases the share of labor in national income

- Total wage effect equals

$$d \ln W = \left[\ln\left(\frac{R}{\gamma_M(N-1)}\right) - \ln\left(\frac{W}{\gamma_L(N)}\right)\right] dN + \left[\ln\left(\frac{W}{\gamma_L(I)}\right) - \ln\left(\frac{R}{\gamma_M(I)}\right)\right] dI + \frac{1}{N-I}(dN - dI), \tag{10}$$

and also for the labor share, we get

$$ds_L = dN - dI.$$

- Labor share stable and wages increase 1:1 w/productivity **iff** new tasks, N, introduced at same rate as automation, I

The Endogenous Evolution of New Tasks

Some good reasons why new tasks, N, may keep up with automation

- Rapid automation may endogenously generate incentives for firms to introduce new labor-intensive tasks (Acemoglu and Restrepo, 2016)
- Some automation technology platforms, especially AI, may facilitate the creation of new tasks
- But it is also possible that we are heading to a future with a lower range of tasks done by human labor, $N - I$

Summary: Four Forces at Play

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Summary: A Nuanced View of Technological Change + Trade

1. **Welfare:** Technological change or trade/outsourcing only Pareto improving in restrictive special cases
2. **Disruptive:** process is *disruptive* – displacement almost inevitable
3. **Speed of adjustment:** Gains are typically diffuse and possibly slow-moving—demand effects, income effects, capital deepening
4. **Concentrated impacts:** Harms likely more immediately felt, concentrated among those displaced
5. **New tasks:** Speed/extent of creation of ‘new tasks’ highly uncertain

NEWS IN BRIEF

Chinese Factory Workers Fear They May Never Be Replaced With Machines

3/19/14 10:22am • SEE MORE: NEWS

SUZHOU, CHINA—Expressing growing concerns about their future job security, factory workers across China reported this week that they are deeply worried they may never lose their menial, hazardous positions on product assembly lines to automated machinery. “It’s a frightening prospect, but I’m starting to seriously believe that the day I find myself replaced by a robot is never coming,” 22-year-old Wintek employee Jie Liu

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A Ricardian Model of Skills, Tasks and Technologies
Production technology: Tasks into goods

- Static environment with a unique final good, Y
- Y produced with continuum of *tasks* on the unit interval, $[0, 1]$
- Cobb-Douglas technology mapping tasks the final good:

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

  where $y(i)$ is the "service" or production level of task i.
- Price of the final good, Y, is numeraire.

A Ricardian Model of Skills, Tasks and Technologies
Supply of skills to tasks

Three types of labor: High, Medium and Low

- Fixed, inelastic supply of the three types. Supplies are L, M and H
- We later introduce capital or technology (embedded in machines)

Each task on continuum has production function

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

- A terms are factor-augmenting technologies
- $\alpha_L(i)$, $\alpha_M(i)$ and $\alpha_H(i)$ are *task productivity schedules*
- For example, $A_L\alpha_L(i)$ is the productivity of low skill workers in task i, and $l(i)$ is the number of low skill workers allocated task i.

A Ricardian Model of Skills, Tasks and Technologies

Role of comparative advantage

- All tasks can be performed by low, medium or high skill workers

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

But comparative advantage differs $\{\alpha_L(i), \alpha_M(i), \alpha_H(i)\}$

- **Assumption:** $\alpha_L(i)/\alpha_M(i)$ *and* $\alpha_M(i)/\alpha_H(i)$ *are continuously differentiable and strictly decreasing*
- Higher indices correspond to "more complex" tasks
- In all tasks, H has absolute advantage relative to M, M has abs. adv. relative to L
- But *comparative advantage* determines task allocations

A Ricardian Model of Skills, Tasks and Technologies

Equilibrium objects: Task thresholds, I_L, I_H

- In any equilibrium there exist I_L and I_H such that $0 < I_L < I_H < 1$ and for any $i < I_L$, $m(i) = h(i) = 0$, for any $i \in (I_L, I_H)$, $l(i) = h(i) = 0$, and for any $i > I_H$, $l(i) = m(i) = 0$

Allocation of tasks to skill groups determined by I_H, I_L

- Tasks $i > I_H$ will be performed by high skill workers (Abstract)
- Tasks $i < I_L$ will be performed by low skill workers (Manual)
- Middle tasks $I_L \leq i \leq I_H$ will be performed by medium skill workers (Routine)

Boundaries of these sets are endogenous

- Given skill supplies, firms (equivalently workers) decide which skills perform which tasks $\rightarrow$ *Substitution of skills across tasks*.

Three equilibrium conditions

1. **Law of one price for skills**
2. **Equal division of labor among tasks within a skill group**
3. **No arbitrage between tasks**

Three equilibrium conditions

1. **Law of one price for skills**

   - Let $p(i)$ denote the price of services of task i. In equilibrium all tasks employing L workers must pay them the same wage, w_L, and similarly for H and L:

$$W_L = p(i) A_L \alpha_L(i) \text{ for any } i < I_L.$$

$$W_M = p(i) A_M \alpha_M(i) \text{ for any } I_L < i < I_H.$$

$$W_H = p(i) A_H \alpha_H(i) \text{ for any } i > I_H.$$

Three equilibrium conditions

1. **Law of one price for skills**

- In equilibrium all tasks employing L workers must pay them the same wage, w_L, and similarly for H and L:

$$W_L = p(i) A_L \alpha_L (i) \text{ for any } i < I_L.$$

- This has a convenient implication:
  - $p(i)\alpha_L(i) = p(i')\alpha_L(i') \equiv P_L$ for any $i, i' < I_L$
  - $p(i)\alpha_M(i) = p(i')\alpha_M(i') \equiv P_M$ for any $I_H > i, i' > I_L$
  - $p(i)\alpha_H(i) = p(i')\alpha_H(i') \equiv P_H$ for any $i, i' > I_H$

Three equilibrium conditions

2. Equal division of labor among tasks within a skill group

- The Cobb-Douglas technology implies:

$$p(i)y(i) \quad = \quad p(i')y(i')$$

- Noting that

$$y\left(i\right) = A_L \alpha_L\left(i\right) l\left(i\right) \text{ for any } i < I_L$$
$$P_L = p\left(i\right)\alpha_L\left(i\right) \text{ for any } i < I_L$$
$$\Rightarrow p\left(i\right) y\left(i\right) = P_L A_L l\left(i\right)$$

- Substituting

$$P_L A_L l\left(i\right) = P_L A_L l\left(i'\right)$$
$$\Rightarrow l\left(i\right) = l\left(i'\right) \text{ for any } i, i' < I_L$$

Three equilibrium conditions

2. **Equal division of labor among tasks within a skill group**

$$l(i) = l(i')$$

- which implies

$$l(i) = \frac{L}{I_L} \text{ for any } i < I_L,$$
$$m(i) = \frac{M}{I_H - I_L} \text{ for any } I_H > i > I_L,$$
$$h(i) = \frac{H}{1 - I_H} \text{ for any } i > I_H.$$

- Any two tasks performed exclusively by workers of one skill group use identical amounts of labor, equal to the group's total labor supply divided by the fraction of the task continuum performed by the group.

Three equilibrium conditions

3. No arbitrage between tasks

- Start with observation that wages equal marginal products:

$$W_L = P_L A_L = A_L p(i) \alpha_L(i) \text{ for } i < I_L$$

$$W_M = P_M A_M = A_M p(i) \alpha_M(i) \text{ for } I_L < i < I_H$$

$$W_H = P_H A_H = A_H p(i) \alpha_H(i) \text{ for } i > I_H$$

Three equilibrium conditions

3. No arbitrage between tasks

- The threshold task I_H must be such that it can be profitably produced using either H or M workers, and similarly for the threshold task I_L:

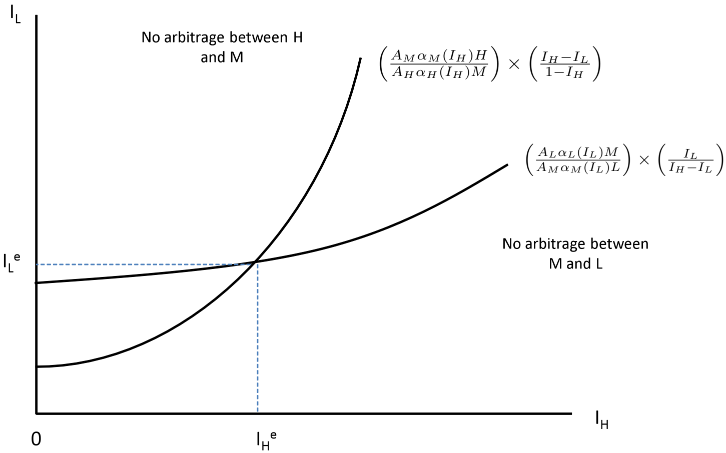
$$\begin{aligned} A_H \alpha_H (I_H) H / (1 - I_H) &= A_M \alpha_M (I_H) M / (I_H - I_L) \\ A_M \alpha_M (I_L) M / (I_H - I_L) &= A_L \alpha_L (I_L) L / I_L \end{aligned}$$

- Implies

$$P_H A_H H / (1 - H) = P_M A_M M / (I_H - I_L)$$
$$P_M A_M M / (I_H - I_L) = P_L A_L L / (I_L)$$

No Arbitrage Across Skill Groups: Relative Cost of Producing Marginal Task(s) Rising in Task Threshold(s)

Figure 22. Determination of Equilibrium Threshold Tasks



Relative Supply and Demand for Skills Across Tasks

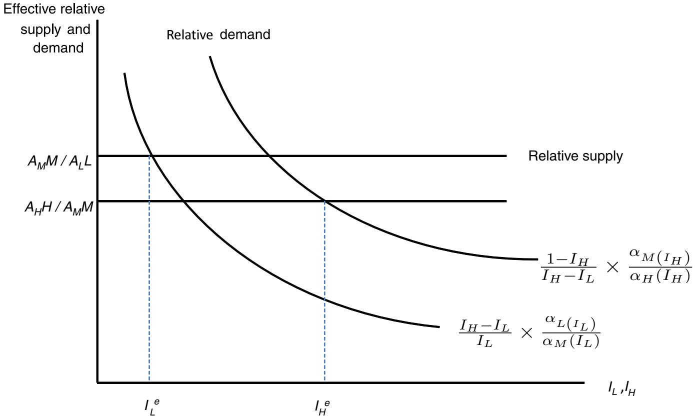


Figure 23 ***Equilibrium allocation of skills to tasks.***

Three equilibrium conditions

3. No arbitrage between tasks

$$P_H A_H H / (1 - I_H) = P_M A_M M / (I_H - I_L)$$
$$P_M A_M M / (I_H - I_L) = P_L A_L L / (I_L)$$

- Substituting

$$W_H = P_H A_H, \; W_M = P_M A_M, \; W_L = P_L A_L$$

$$W_H H / (1 - H) = W_M M / (I_H - I_L)$$
$$W_M M / (I_H - I_L) = W_L L / (I_L)$$

$$\Rightarrow \frac{W_H}{W_M} = \left(\frac{1 - I_H}{I_H - I_L}\right) \frac{L}{H}, \; \frac{W_M}{W_L} = \left(\frac{I_H - I_L}{I_L}\right) \frac{L}{M}, \; \frac{W_H}{W_L} = \left(\frac{I_H}{I_L}\right) \frac{L}{H}$$

A Ricardian Model of Skills, Tasks and Technologies

- These three conditions [law of one price, no arbitrage, equal shares] imply that relative wages are solely a function of labor supplies and task thresholds $w_J = w_J \left[I_H, I_L | H, M, L, A_H, A_M, A_L, \alpha_H(\cdot), \alpha_M(\cdot), \alpha_L(\cdot) \right]$ for $J \in [H, M, L]$:

$$\begin{aligned} \frac{w_H}{w_M} &= \left(\frac{1 - I_H}{I_H - I_L} \right) \left(\frac{H}{M} \right)^{-1}, \\ \frac{w_M}{w_L} &= \left(\frac{I_H - I_L}{I_L} \right) \left(\frac{M}{L} \right)^{-1} \end{aligned}$$

- So, labor supplies L, M, H plus compare adv. $\alpha(L), \alpha(M), \alpha(L)$ determine task allocation, I_L and I_H, and hence wages.
- It's that simple!

Canonical Skill-Biased Technical Case – Rising A_H (relative to A_M, A_L)

1. **A rise in A_H (SBTC)**
2. **A rise in high-skilled labor supply**
3. **Analogous comparative statics for rise in A_L or A_H**
4. **What about a rise in A_M or M on W_H/W_L?**

The response of task location to technology and skill supplies

- **An increase in the supply of H labor or an H-augmenting technical change A_H**
  1. Own task share $\frac{dI_H}{d\ln A_H} = \frac{dI_H}{d\ln H} < 0$
  2. L task share: $\frac{dI_L}{d\ln A_H} = \frac{dI_L}{d\ln H} < 0$
  3. M task share: $\frac{d(I_H - I_L)}{d\ln A_H} = \frac{d(I_H - I_L)}{d\ln H} < 0$
- **Analogously for $d\ln L$ or $d\ln A_L$**
  - $\frac{dI_H}{d\ln A_L} = \frac{dI_H}{d\ln L} > 0$, $\frac{dI_L}{d\ln A_L} = \frac{dI_L}{d\ln L} > 0$
  - and $\frac{d(I_H - I_L)}{d\ln A_L} = \frac{d(I_H - I_L)}{d\ln L} < 0$

The response of wages to skill supplies

- **Impact of an increase in the supply of labor on relative wages**
  1. **High skill supply:** $\frac{d\ln(w_H/w_L)}{d\ln H} < 0,\ \frac{d\ln(w_H/w_M)}{d\ln H} < 0$
  2. **Medium skill supply:** $\frac{d\ln(w_H/w_M)}{d\ln M} > 0,\ \frac{d\ln(w_M/w_L)}{d\ln M} < 0$
  3. **Low skill supply:** $\frac{d\ln(w_M/w_L)}{d\ln L} > 0,\ \frac{d\ln(w_H/w_L)}{d\ln L} > 0$
- **What about** $\frac{d\ln(w_H/w_L)}{d\ln M}$ **...?**

The response of wages to factor-augmenting technological changes

- **Impact of technological changes on relative wages**

  1. H **augmenting:** $\frac{d \ln(w_H/w_L)}{d \ln A_H} > 0$, $\frac{d \ln(w_H/w_M)}{d \ln A_H} > 0$, $\frac{d \ln(w_M/w_L)}{d \ln A_H} < 0$;
  2. M **augmenting:** $\frac{d \ln(w_H/w_M)}{d \ln A_M} < 0$, $\frac{d \ln(w_M/w_L)}{d \ln A_M} > 0$
  3. L **augmenting:** $\frac{d \ln(w_H/w_L)}{d \ln A_L} < 0$, $\frac{d \ln(w_H/w_M)}{d \ln A_L} > 0$, $\frac{d \ln(w_M/w_L)}{d \ln A_L} < 0$;

- **What about** $\frac{d \ln(w_H/w_L)}{d \ln A_M}$ **...?**

Change in productivity or supply of middle-skill workers

What happens when either M or A_M rises?

- Depends critically on this term

$$\beta_H(I) \equiv \ln \alpha_M(I) - \ln \alpha_H(I), \beta_L(I) \equiv \ln \alpha_L(I) - \ln \alpha_M(I)$$

- β are comp. advantage of L versus H workers in M tasks
- $\beta_L'(I_L) I_L = \partial \beta_L / \partial I_L$ and $\beta_H'(I_H) I_H$
- If $\beta_L'(I_L)$ is low relative to $\beta_H'(I_H)$, high skill workers have *strong comparative advantage* for tasks above I_H

Hence, rise in M displaces L workers more than H iff

$$\frac{d \ln (w_H/w_L)}{d \ln M} > 0 \text{ iff } |\beta_L'(I_L) I_L| < |\beta_H'(I_H)(1 - I_H)|$$

Implicitly this occurs because I_L falls more than I_H rises

How Technology Enters

Easy to model a 'task replacing technology'

- Both K and Labor can supply tasks—all perfect substitutes
- K supplies task if can perform more cheaply than L, M, or H.

Example: Routine Task Replacing technology

- Capital that out-competes M in a subset of tasks i' in the interval $I_L < i' < I_H$

Own wage effects

- Immediately lowers relative wage of M by narrowing set of M tasks

Cross-price effects on W_L and W_H?

- Again depend on $|\beta_L'(I_L) I_L| \gtreqless |\beta_H'(I_H)(1 - I_H)|$
- If M workers better suited to L than H tasks, then W_H/W_L rises

Routine Task Replacing Technology

Focal case

- Task replacing technology concentrated in middle-skill/routine tasks
- Strong comparative advantage of H relative to L at respective margins with M

Leads to wage and employment 'polarization'

1. Wages:
   - Middle wages fall relative to top and bottom.
   - Top rises relative to bottom
2. Employment:
   - Middle-skill/routine tasks mechanized
   - Declining labor input in Routine tasks
   - Given comparative advantage, middle-skill workers move disproportionately downward in task distribution.

Offshoring

Offshoring works identically to capital that competes for tasks

- In this sense, model is akin to Grossman and Rossi-Hansberg (2008)
- But the comparative advantage setup here is much more general

Two further extensions

Endogenous choice of skills

- Workers can have a bundle of l, m, and h skills
- When comparative advantage of one skill sufficiently eroded, may switch skills
- Example: Former manager, now driving delivery truck

Endogenous technical change

- Endogenous tech change favoring *skills* is well understood from Acemoglu (1998, 2007)
- We also consider endogenous technical change *favoring tasks* in this model

Ricardian Model: Summary

Model's inputs

1. Explicit distinction between *skills* and *tasks*
2. *Comparative advantage* among workers in different tasks
3. Multiple sources of competing task 'supplies'

What the model delivers

- A natural concept of occupations (bundles of tasks)
- An endogenous mapping from skill to tasks via comparative advantage
- Technical change (offshoring) that can raise and *lower* wages
- Migration of skills across tasks as technology changes
- Polarization of wages and employment as *one possible outcome*

Conclusions

Canonical model has been a conceptual and empirical success

- But silent on some key phenomena of interest
  - Falling real wages for some groups
  - Non-monotone wage changes
  - Polarization of employment
  - Reallocation of skill groups across occupations

Additional insights gained by

1. Distinguishing between *skills* and *tasks*
2. Allowing for *comparative advantage* among workers in different tasks
3. Allowing for multiple sources of competing task 'supplies'