UNIVERSITÀ DEGLI STUDI DI FERRARA
- EX LABORE FRUCTUS -

DEPARTMENT OF ECONOMICS & MANAGEMENT

Economics of Innovation
Innovation and Employment

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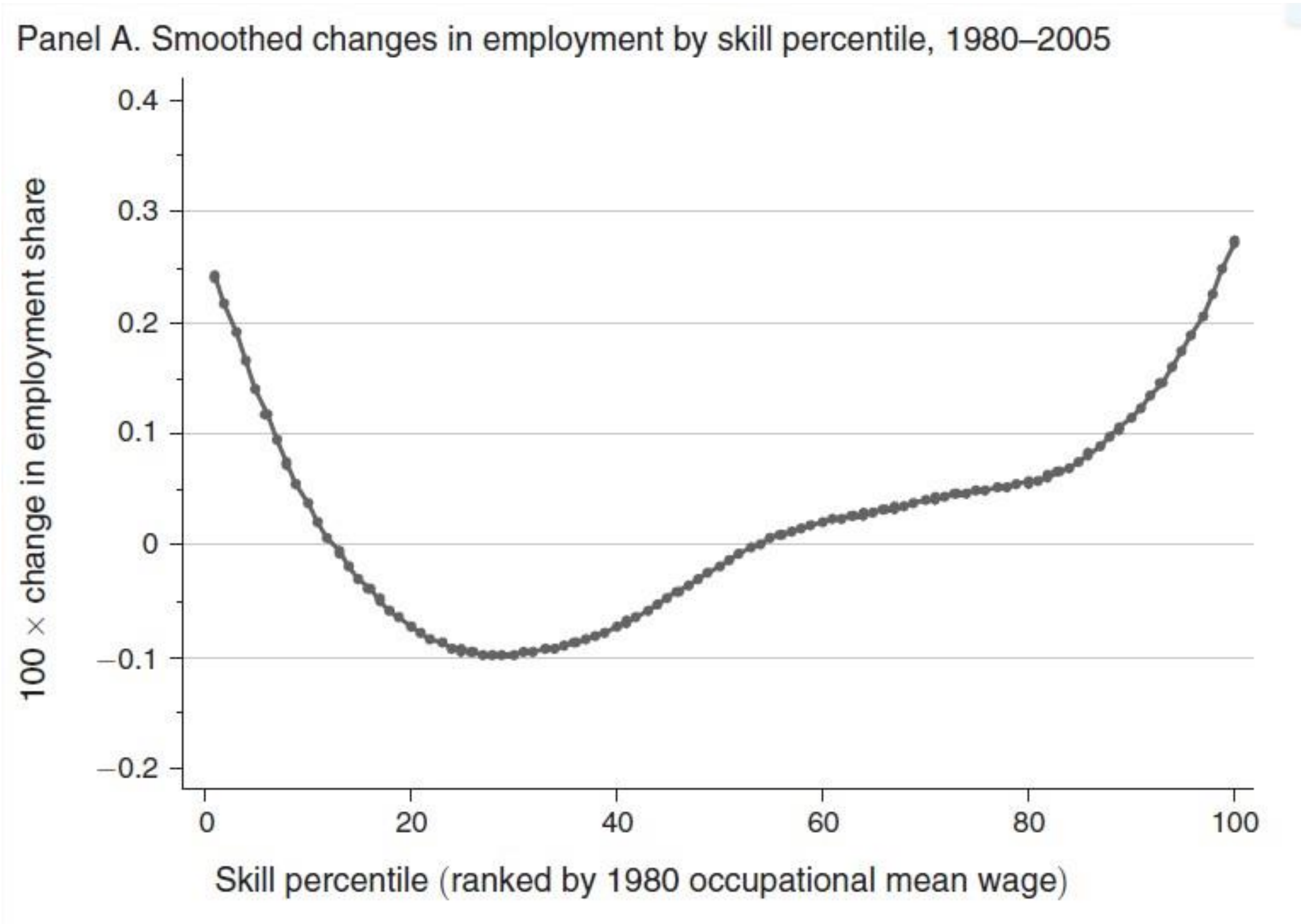
02/11/2017

Are robots stealing our jobs?

The issue at stake

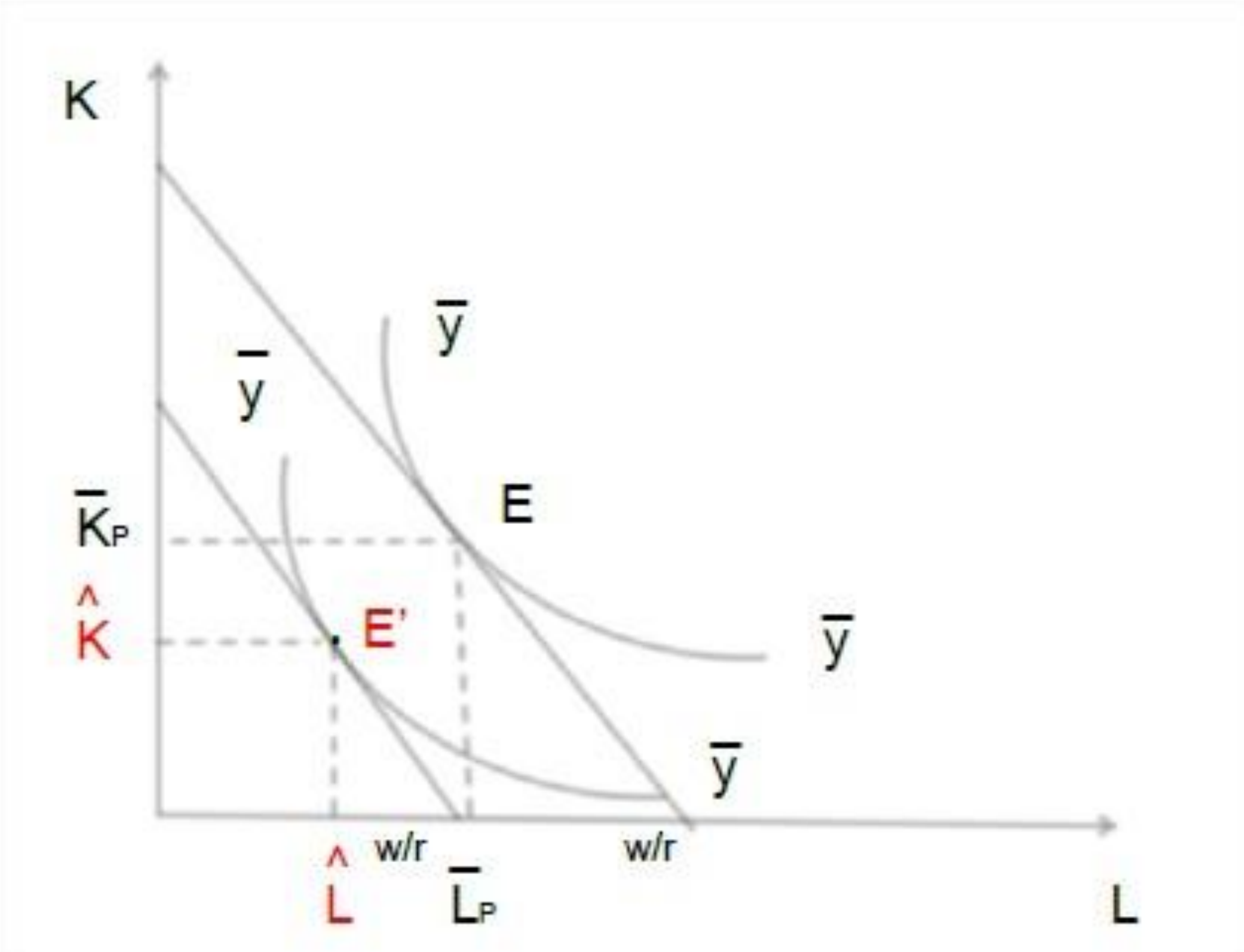


Autor and Dorn, 2013

Innovation and employment: Theory (Vivarelli, 2012)

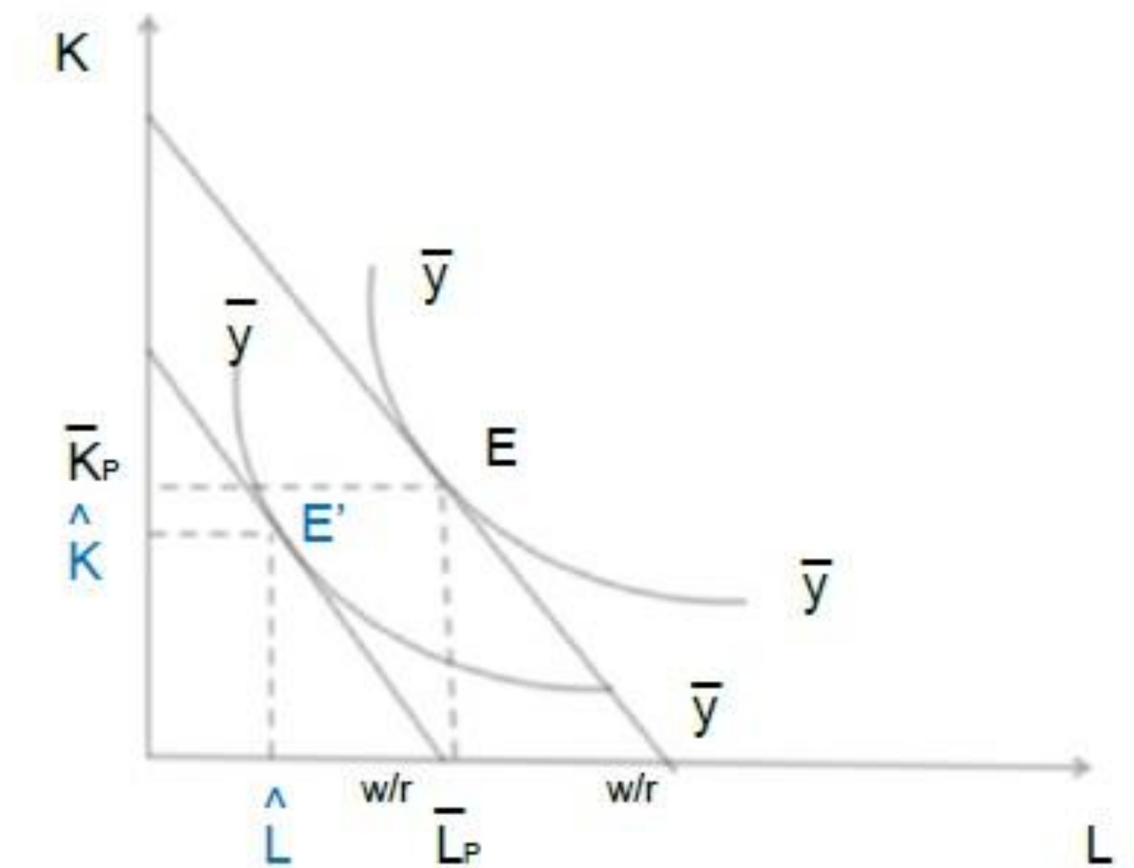
- Technological change (TC) allows to produce at least the same amount of products with less capital and labour.
- "Technological unemployment"
- Thus, employment always decreases as an **direct** effect of technological change
- What is a 'direct' effects?

Neutral TC



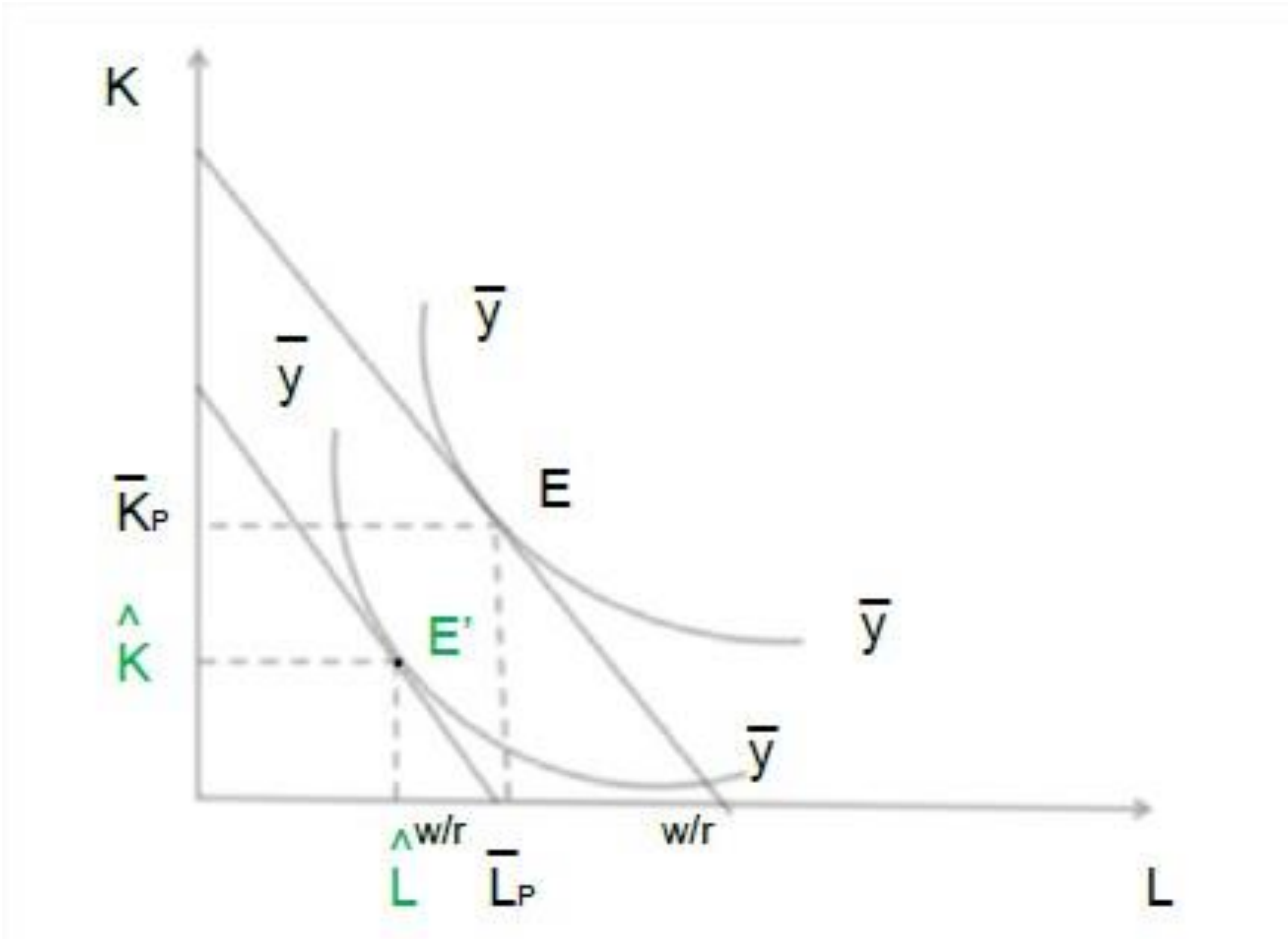
Vivarelli 2012

Labour-saving TC



Vivarelli 2012

Capital-saving TC



Vivarelli 2012

Comments

- L^(hat) is always lower than Lp
- Only drastic capital-saving TC is able to move the equilibrium E’ to the right of the initial level of employment.
- These are the direct effects of process innovation
- Are there market mechanisms able to counterbalance this direct (negative) effect?

Compensation theory – Marx (1961)

- Six main compensation mechanisms via:
  - Capital good sector
  - Decrease in prices
  - New investments
  - Decrease in wage
  - Increase in incomes
  - New products

Compensation mechanism (1)

- …**via capital good sector**
  - Sometimes technologies are developed in one sector and used in others.
  - Process innovations may cause jobs destruction in the **user** industries whereas it enhances jobs in the sectors where the new machines are **produced** (Say, 1964)
  - E.g. PC displaces workers in banks whereas it increases jobs in Silicon Valley

Compensation mechanism (2)

- **…via decrease in prices**
  - Process innovations lead to a decrease in marginal **costs** of production (in the sector where they are used)
  - In **competitive markets** this results in decreasing **prices**
  - In turn this stimulates an increase in **demand** for products → increase of employment
  - This mechanism has been re-proposed by neoclassical economists
  - E.g. PC reduces production costs of mobile phones which translates in a reduction of prices. This triggers the demand for mobile phones

Compensation mechanism (3)

- …**via new investments** (Ricardo, 1951)
  - Since the price mechanism is not instantaneous (competitive convergence), there is a gap between the decrease in costs –due to TC- and fall in prices.
  - In between, innovative entrepreneurs accumulate profits which are invested in new production → new jobs

Compensation mechanism(4)

- …**via decrease in wages**
  - The direct negative effect of TC on employment may be compensated by in the labour market through a price adjustment.
  - In the neoclassical framework a decrease in wages spurs labour demand
  - Wicksell (1961: 137), followed by Hicks (1932: 56), Pigou (1933: 256) and Robbins (1934: 186)

Compensation mechanism (5)

- …**via increase in incomes**
  - Unions take part in the distribution of the fruits of TC.
  - A portion of the cost savings translates into higher income and consumption
  - This leads to increase in employment

Compensation mechanism (6)

- **…via new products**
  - Process innovations stimulate the creation of new products
  - This favours the creation of new industries leading to increase in employment
  - Welfare effect vs substitution effect

"Entirely new branches of production, creating new fields of labor, are also formed, as the direct result either of machinery or of the general industrial changes brought about by it." (Marx, 1961: 445).

Comments

- There are different mechanisms which compensate the initial labour-saving effect of TC.
- Compensation can only be partial
- However, the '**net effect**' determines whether TC decreases or increases employment
- Economists do not have a clear-cut answer to the question:
- **Which are the employment effects of innovation?**

Introduction

- Two features characterise our economies in the past (and to some extent nowadays)
  - Job polarisation
  - Wage inequalities
- Changes in the wage structure brought about increasing wage inequality in the US (but also elsewhere)
  - Wage differences linked to education: graduated earn more
  - (among those with lower levels of education) average wage increased more for older workers
- Decrease in wage inequality at some demographic levels:
  - In the 80s the average wage of women increased more than the average wage for men (8%(

TABLE I

U. S. REAL WEEKLY WAGE CHANGES FOR FULL-TIME WORKERS, 1963–1987[a]

Group	Change in log average real weekly wage (multiplied by 100)			
	1963–1971	1971–1979	1979–1987	1963–1987
All	19.2	−2.8	−0.3	16.1
Gender:				
Men	19.7	−3.4	−2.4	13.9
Women	17.6	−0.8	6.1	22.9
Education (years of schooling):				
8–11	17.1	0.3	−6.6	10.9
12	16.7	1.4	−4.0	14.1
13–15	16.4	−3.4	1.5	14.4
16+	25.5	−10.1	7.7	23.1
Experience (men):				
1–5 years	17.1	−3.5	−6.7	6.8
26–35 years	19.4	−0.6	0.0	18.8
Education and Experience (men):				
Education 8–11				
Experience 1–5	20.5	1.5	−15.8	6.2
Experience 26–35	19.3	−0.4	−1.9	17.0
Education 12				
Experience 1–5	17.4	0.8	−19.8	−1.6
Experience 26–35	14.3	3.2	−2.8	14.7
Education 16+				
Experience 1–5	18.9	−11.3	10.8	18.4
Experience 26–35	28.1	−4.0	1.8	25.9

a. The numbers in the table represent log changes in mean weekly wages using data from the March Current Population Surveys for 1964–1988. Mean weekly wages for full-time workers in each of 320 sex-education-experience cells were computed in each year. Mean wages for broader groups in each year represent weighted averages of these cell means using a fixed set of weights (the average employment share of the cell for the entire 1963–1987 period). All earnings numbers are deflated by the implicit price deflator for personal consumption expenditures.

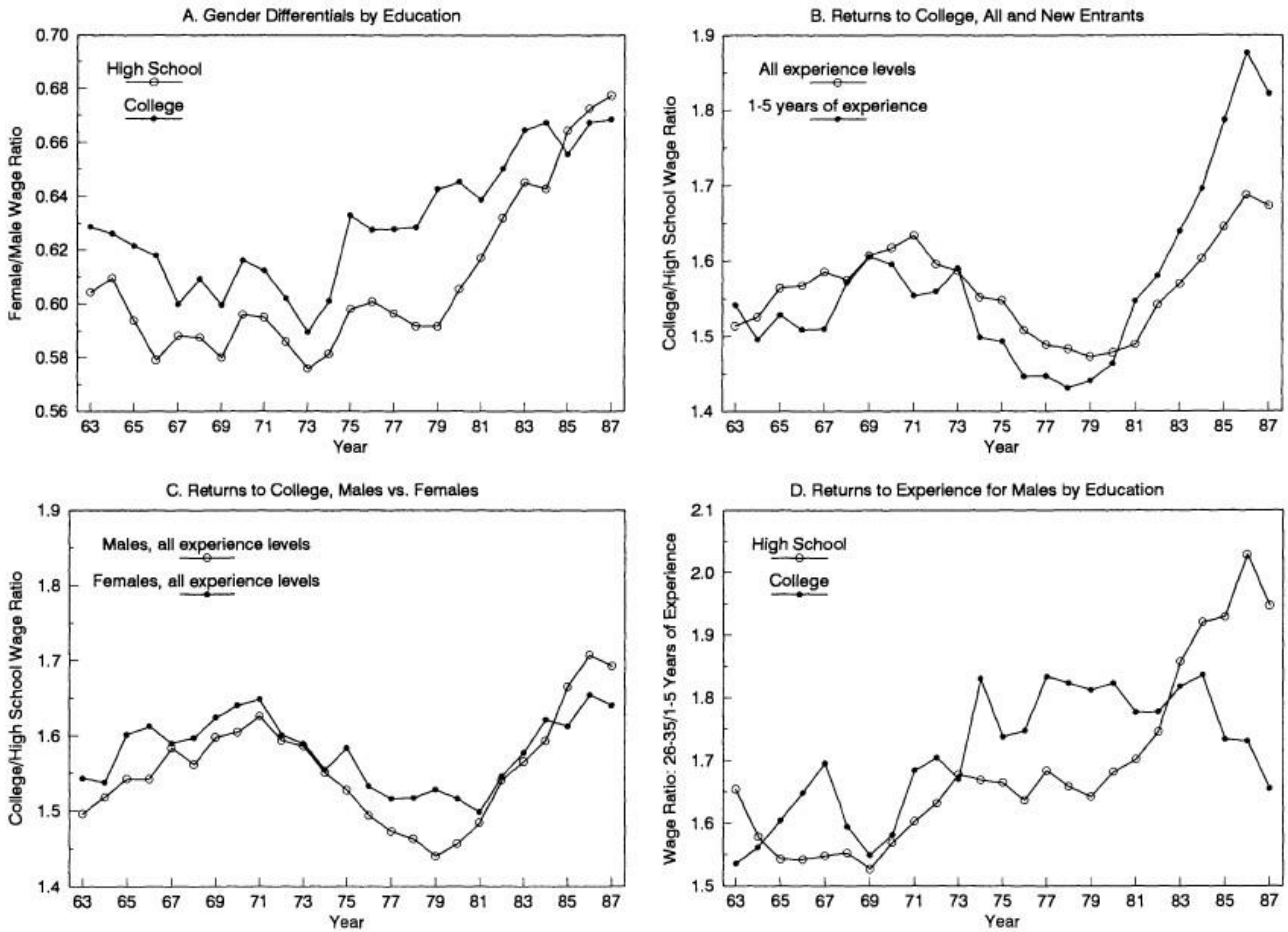


FIGURE I
Major U. S. Relative Wage Changes, 1963–1987

Possible causes

- Why?
  - Changes in labour demand. From low-skilled to high-skilled
  - Technological change – less physical (manual) work
  - Demand for goods – less manufacturing and more services (which require more educated workers and caused gender inequalities)

Canonical model

- Operationalises the demand and supply for skills
- Takes into account 2 groups of workers endowed with 2 different skills (high and low). These 2 groups carry out 2 different tasks which are imperfect substitutes (equipment management vs equipment maintenance)

Skill demand and supply

- Basic assumptions
  1. Two skills, high and low: H, L. Typically college v. high school
  2. No distinction between skills and 'tasks'—Skill is direct input into production
  3. H and L are imperfect productive substitutes: $\sigma > 0$.
  4. Wages are set on the demand curve
- Canonical representation

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

  where A_L and A_H are factor-augmenting technology terms.
- Elasticity of substitution plays key role
  - $\sigma > 1$: H and L are gross substitutes. Rise in A_H / A_L is SBTC
  - $\sigma < 1$: H and L are gross complements. *Fall* in A_H / A_L is SBTC

Wages

- Skill premium

$$\ln\left(\frac{W_H}{W_L}\right) = \frac{\sigma-1}{\sigma}\ln\left(\frac{A_H}{A_L}\right) - \frac{1}{\sigma}\ln\left(\frac{H}{L}\right).$$

- Supply and demand visible
  1. $\ln(H/L)$ represents position of supply curve
  2. $\frac{\sigma-1}{\sigma}\ln\left(\frac{A_H}{A_L}\right)$ represents position of demand curve
  3. Impact of supply on wage inequality

$$\frac{\partial \ln(W_H/W_L)}{\partial \ln(H/L)} = -\frac{1}{\sigma}$$

  4. Impact of factor tech Δ on wage inequality

$$\frac{\partial \ln(W_H/W_L)}{\partial \ln(A_H/A_L)} = \frac{\sigma-1}{\sigma} > 0 \text{ iff } \sigma > 1$$

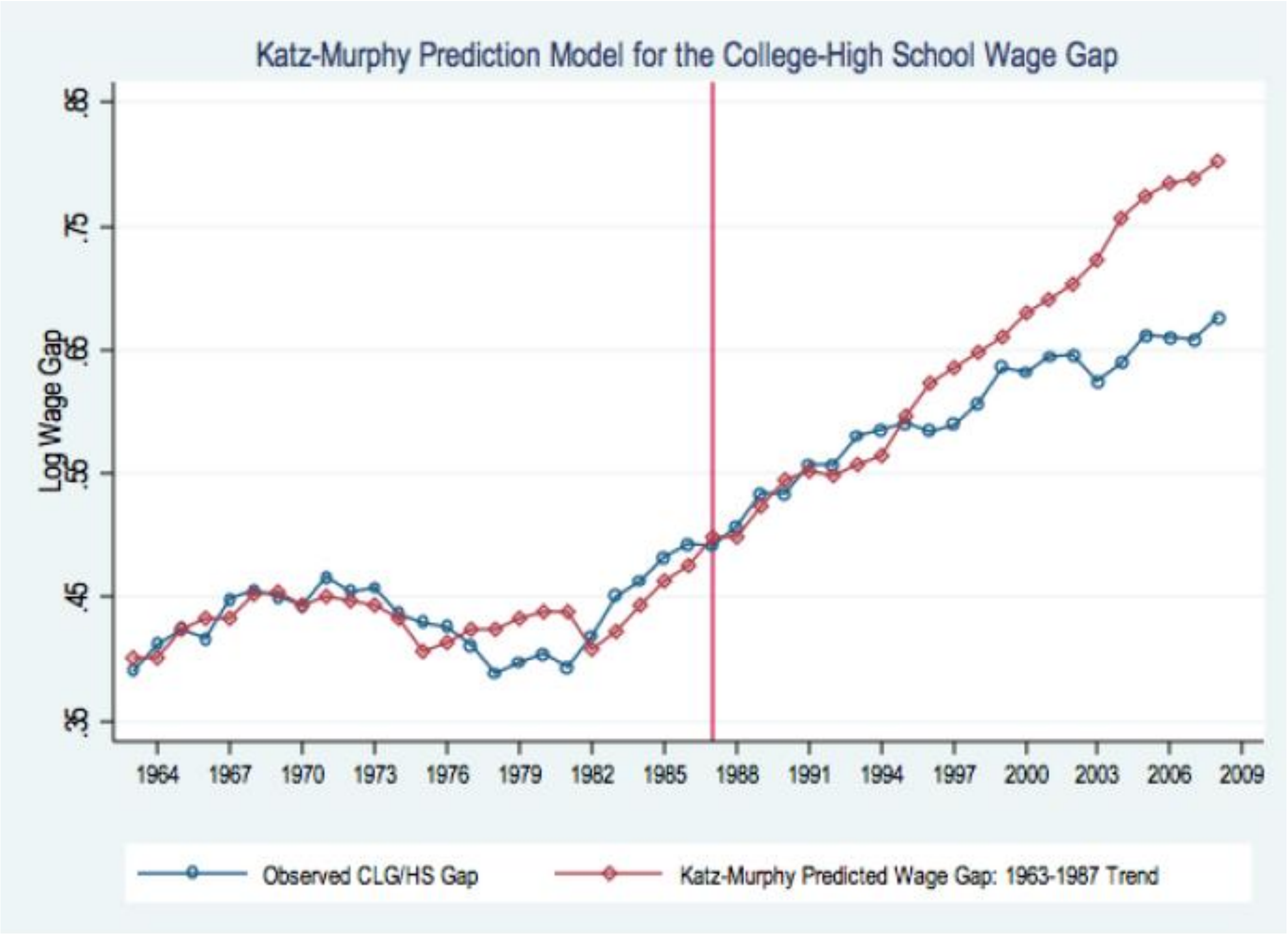
Consensus is that $\sigma \in (1.4, 2.5)$, so technology that raises relative output of H also raises its relative wage.

Findings

Some key testable predictions

1. Rise in supply of H/L reduces skilled wage differential
   - $\partial \ln \left(w_H / w_L \right) / \partial \ln \left(H/L \right) = -1/\sigma < 0$
2. Rise in supply of H/L also *raises* real wage of L: $\partial w_L / \partial H/L > 0$
   - This follows from imperfect substitutability between H and L.
3. Factor augmenting tech Δ always raises wages of L workers: $\partial W_L / \partial A_L > 0$ and $\partial W_L / \partial A_H > 0$.
   - This also follows from imperfect substitutability.
4. *Predictions of this model are always monotone in skill*
   - A bit tautological since there are only two skills/wages
   - But assume a continuum of efficiencies in ea. skill group: still true
   - *Loosely:* Wage inequality is either rising or falling in this model, *not both*

Findings

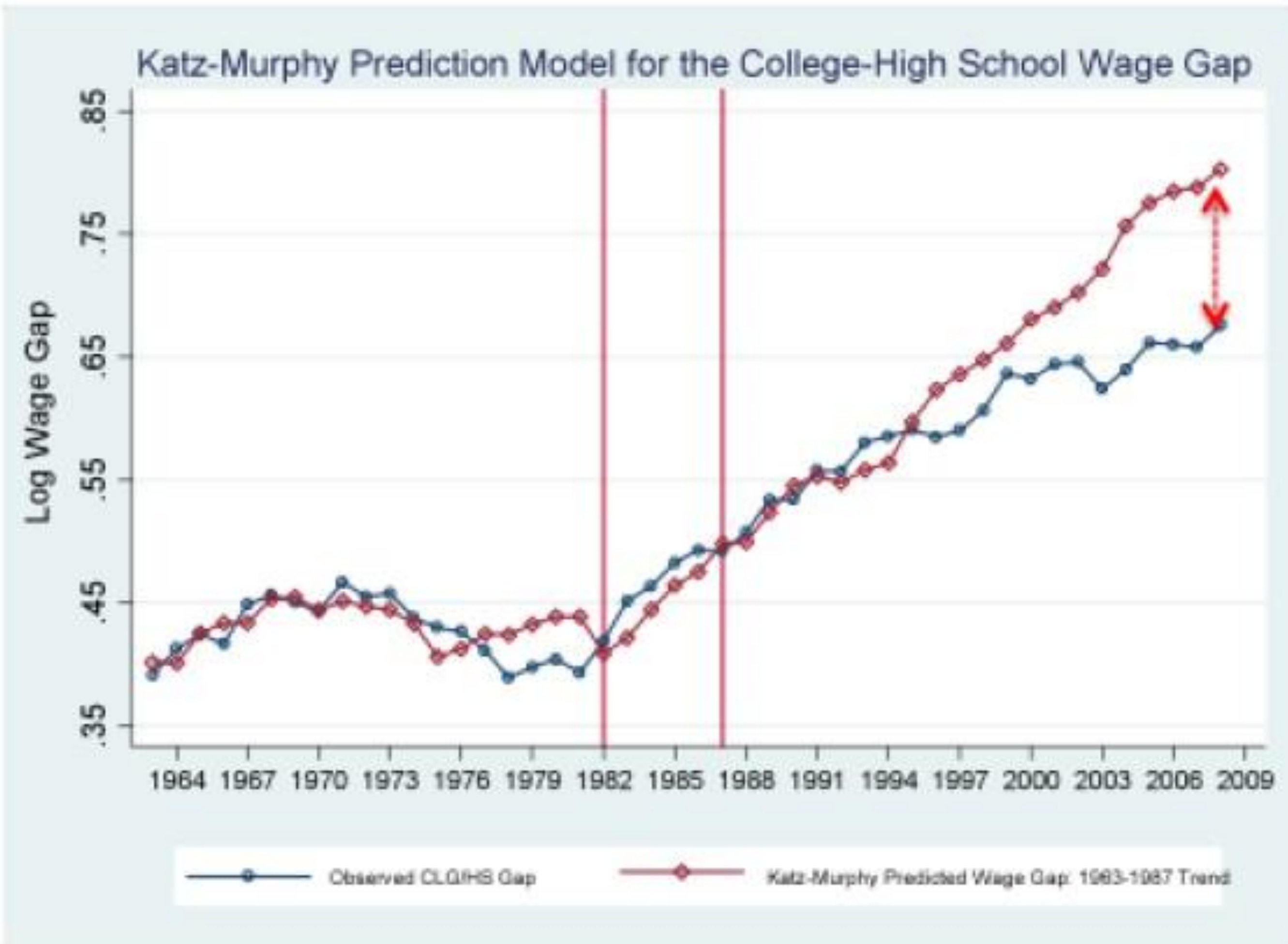


Katz-Murphy Prediction Model for the College-High School Wage Gap
Log Wage Gap
.35
.45
.55
.65
.75
.85
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
Observed CLG/HS Gap
Katz-Murphy Predicted Wage Gap: 1963-1987 Trend

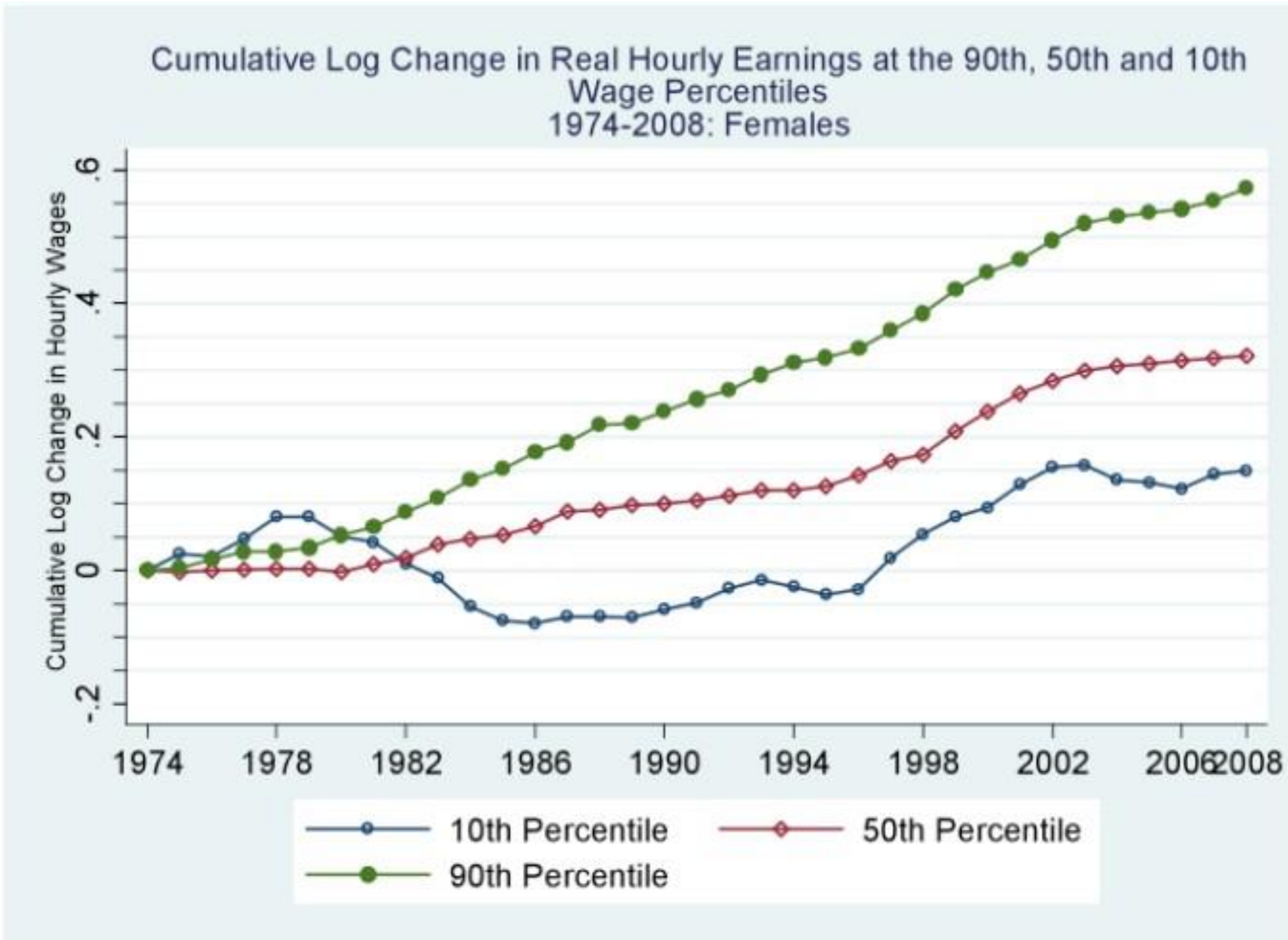
Weaknesses

- Some weaknesses related to the canonical model and its operationalisation:
  - Wage inequality increased less than foreseen
  - Real wage decreased for some groups
  - The relationship between wage changes and skills is non monotonic
  - Polarisation is non monotonic

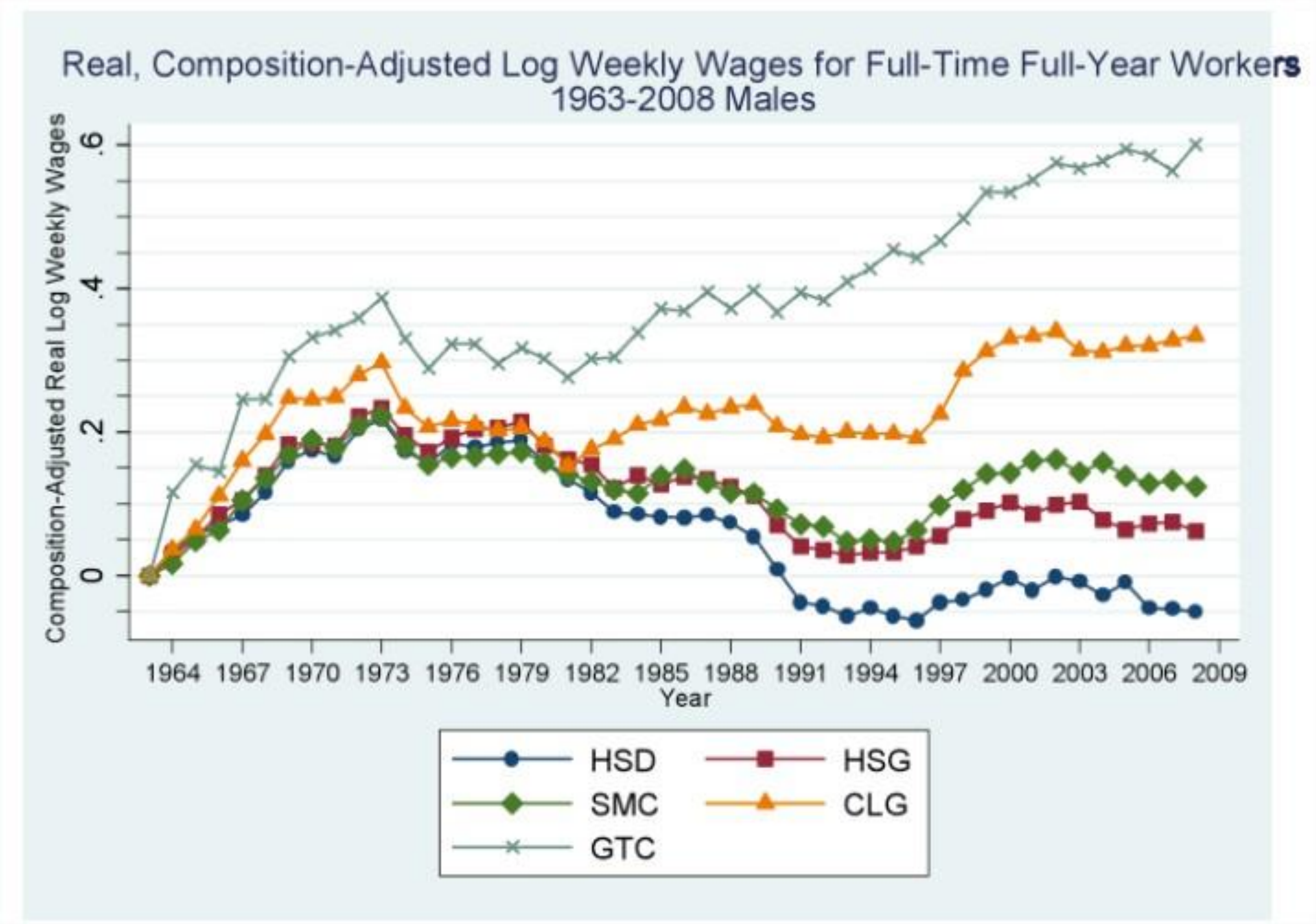
Wage inequality increased less than what has been forecasted by the canonical model



Real wage decreased for some groups

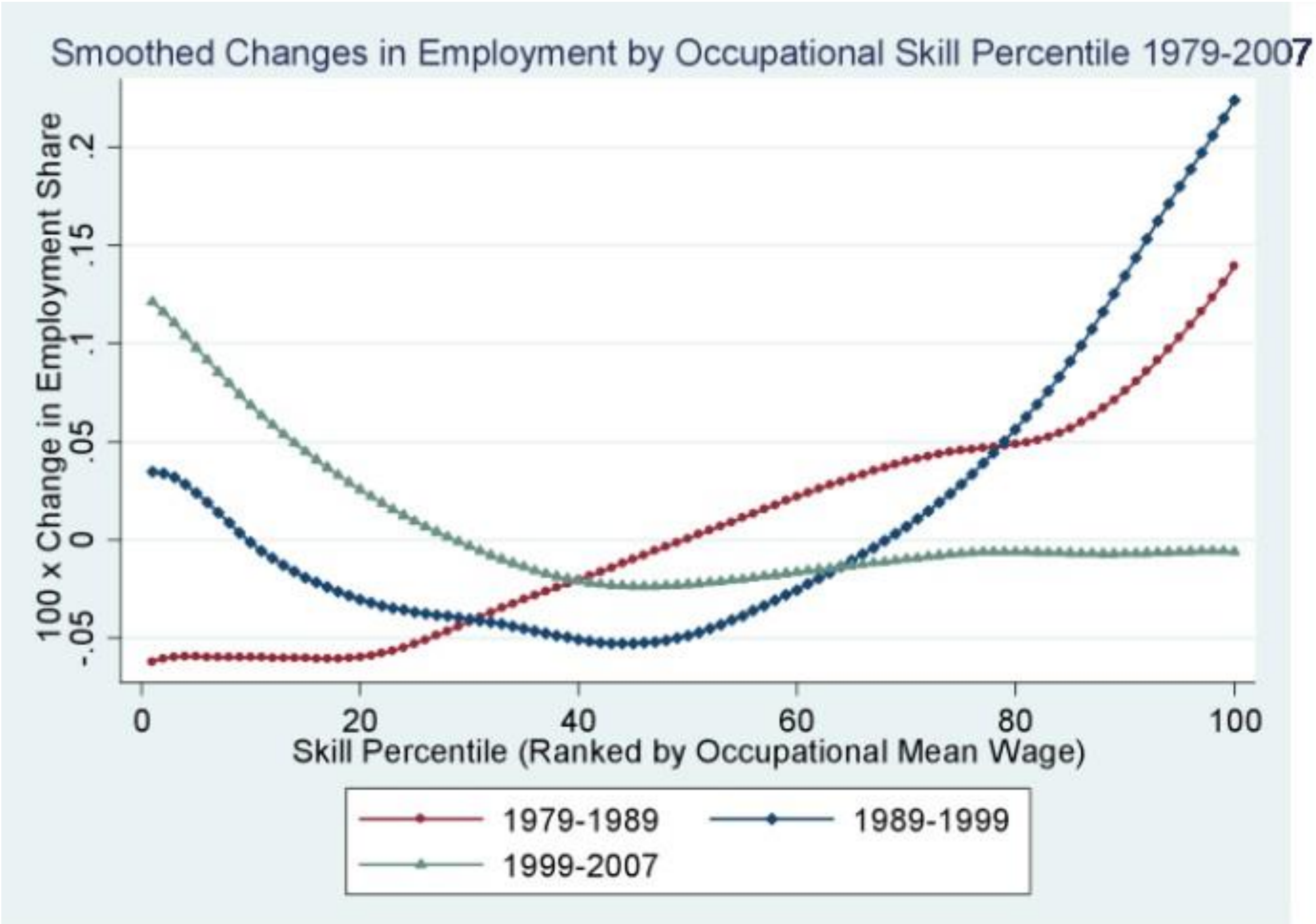


- The relationship between wage changes and skills is non monotonic

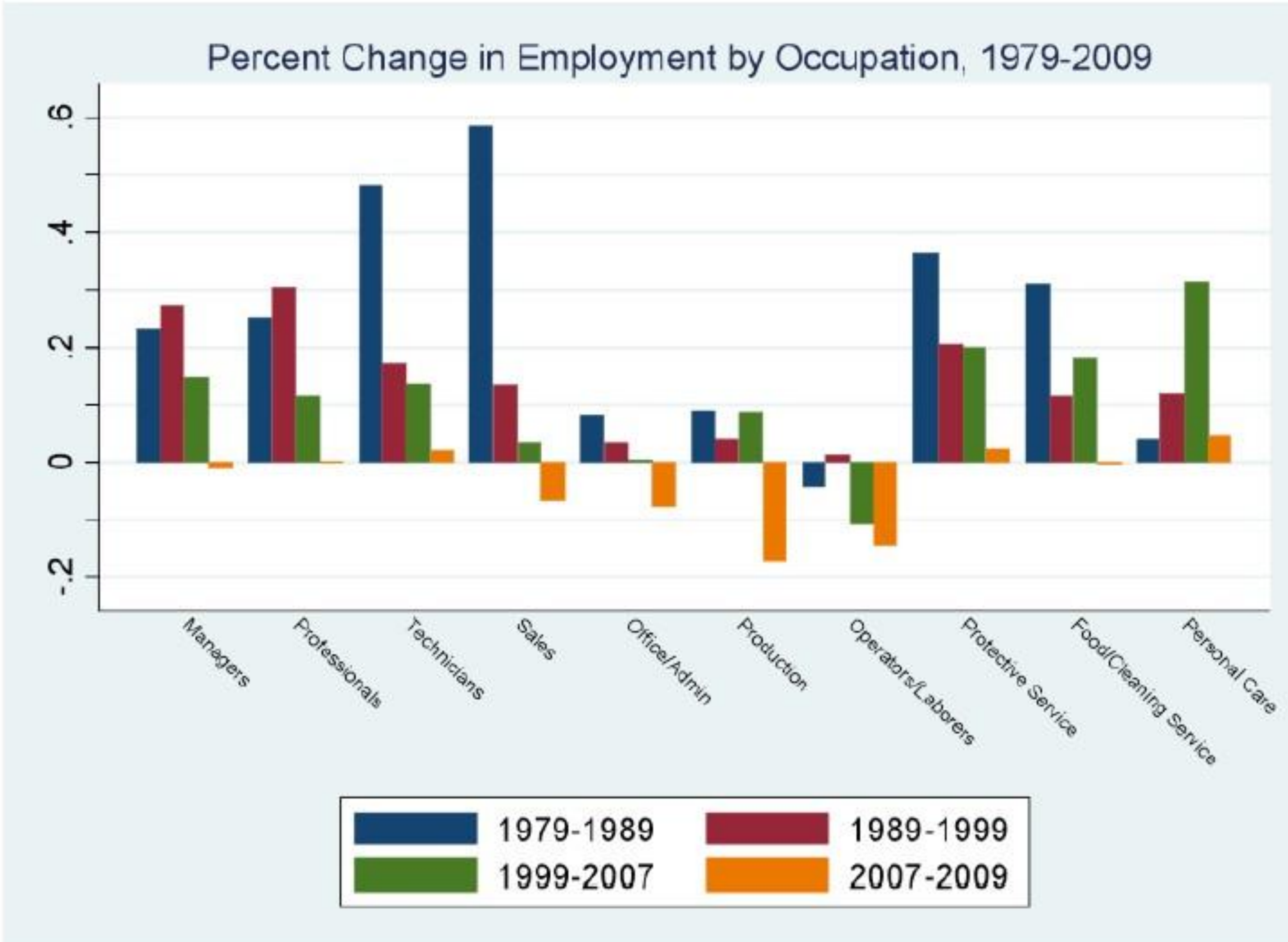


Workers with a lower level of education experienced a decrease in wage

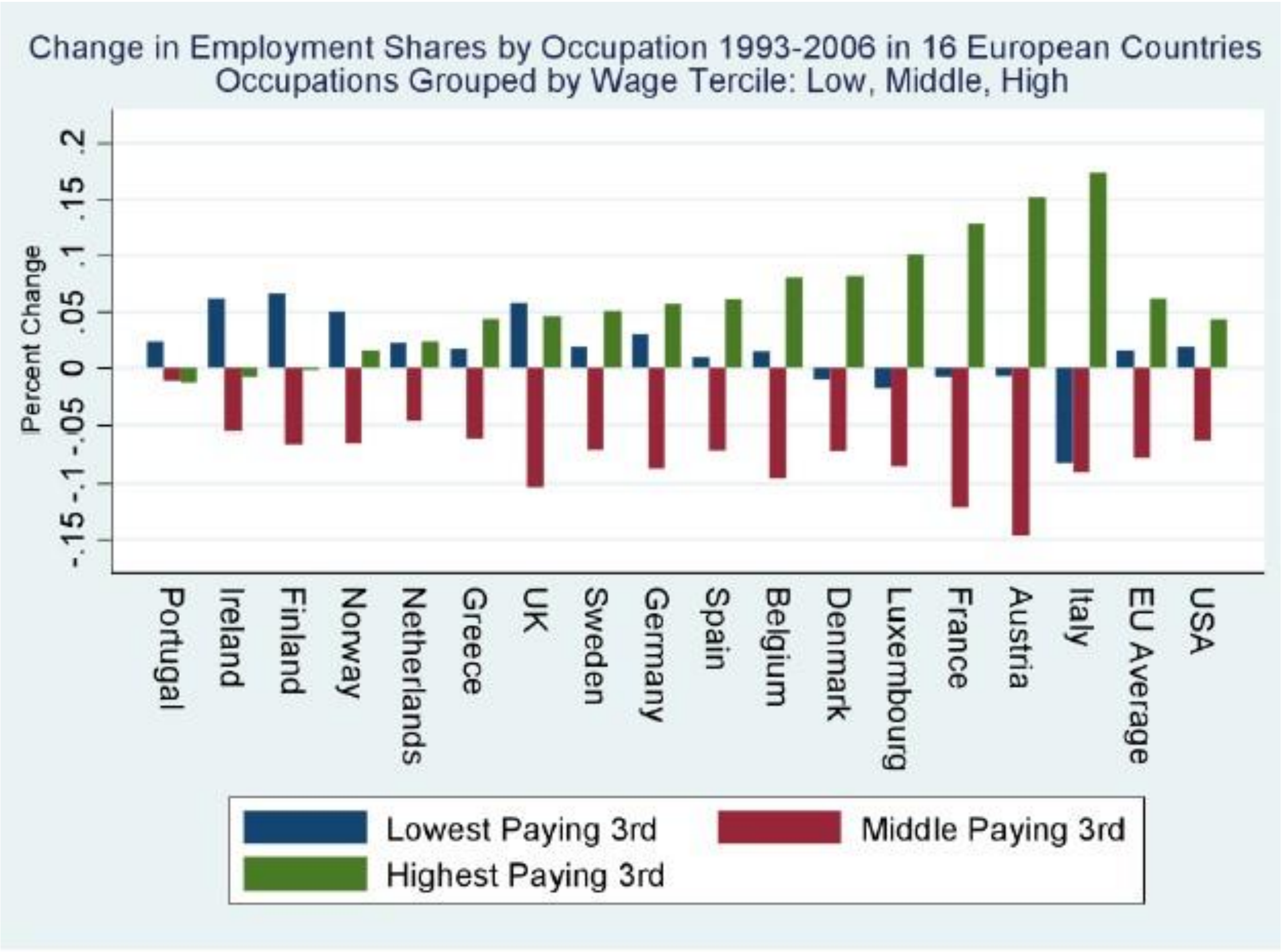
- Job polarisation



- Polarisation of the labour market



- Polarisation of the labour market



Beyond the canonical model

- What should the model include to account for these dynamics?
  - Distinguish between tasks and skills
    - task: unit of labour to produce the output
    - Skill: characteristics of the worker who carry out the task
  - Comparative advantage of some workers who carry out a specific task:
    - The link between skill and task is endogenous
  - Task supply:
    - Workers with different skills
    - Machines (routinisation)
    - Offshoring
  - Consider at least 2 levels of skills –> polarisation

Acemoglu and Autor, 2010

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.

Acemoglu and Autor, 2010

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 by skill differs thru* $\alpha_L(i)$, $\alpha_M(i)$, $\alpha_H(i)$

Comparative advantage schedule

- **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

Acemoglu and Autor, 2010

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.*

Acemoglu and Autor, 2010

- Relative wages solely a function of labor supplies and task thresholds

$$\frac{w_H}{w_M} = \left(\frac{1 - I_H}{I_H - I_L}\right)\left(\frac{H}{M}\right)^{-1},$$

$$\frac{w_M}{w_L} = \left(\frac{I_H - I_L}{I_L}\right)\left(\frac{M}{L}\right)^{-1}$$

- 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.

Acemoglu and Autor, 2010

Consider a rise in A_H (SBTC):

- Increase share of tasks done by H
- Raises W_H / W_m and W_H / W_L
- Lowers W_M / W_L! Why? Because H and M are closer substitutes than H and L.

Consider a rise in high-skilled labor supply H:

- Increase share of tasks done by H
- *Lowers* W_H / W_m and W_H / W_L
- Lowers W_M / W_L (Rise in A_H is isomorphic to rise in H)

Identical comparative statics for rise in A_L or L.

How do we explain the effect of technology on labour supply?

From Skill-biased TC to Routine-Biased TC

Introduction

- Correlation between technology development (computerisation) and demand for workers with higher levels of education →SBTC
- But this doesn't explain the causes of this correlation:
  - What type of activities computers carry out?
  - What kind of activities workers carry out using computers?
- Computer can be AI, ICT new machineries, etc.

New theoretical framework

- Computers affect how tasks are carried out by workers and therefore the demand for skills.
- The key point is:
  - What kind of tasks computers are more likely to carry out?
  - How do computers substitute or complement workers' skills
- Answer:
  - Computer substitute humans on a set of specific cognitive and manual tasks. The important thing is that these tasks follow specific rules (algorithm)
  - Computers complement workers in activities such as problem-solving and communication

TABLE I

PREDICTIONS OF TASK MODEL FOR THE IMPACT OF COMPUTERIZATION ON FOUR CATEGORIES OF WORKPLACE TASKS

	Routine tasks	Nonroutine tasks
	Analytic and interactive tasks	
Examples	• Record-keeping • Calculation • Repetitive customer service (e.g., bank teller)	• Forming/testing hypotheses • Medical diagnosis • Legal writing • Persuading/selling • Managing others
Computer impact	• Substantial substitution	• Strong complementarities
	Manual tasks	
Examples	• Picking or sorting • Repetitive assembly	• Janitorial services • Truck driving
Computer impact	• Substantial substitution	• Limited opportunities for substitution or complementarity

What computers do?

- Routine tasks: follow specific, clear and understandable rules. E.g. measurement of the temperature of this room
- Non-routine tasks: These tasks cannot be formalised on an algorithm and are not specific. E.g. drive a car, decrypt human writing

What's new?

- The economic theory has already formalised the fact that some machineries have substitute some workers in routine tasks (Industrial revolution)
- It is important to bear in mind that:
  - Computers have accelerated this substitution
  - May be complementary to non-routine tasks
  - An increase in routinised activities may generate an increase in non-routine labour demand. E.g. coordination and management of the production process
    - Problem solving tasks
    - Communication

Labour demand of routine and non-routine tasks

- Postulates
  - Computer capital is more likely to substitute routine tasks
  - Routine and non-routine tasks are imperfect substitutes
  - An increase in routine inputs increases the marginal productivity of non-routine inputs
- Assumptions: 2 tasks (R and NR)

Cobb-Douglas production function

$$Q = (L_R + C)^{1-\beta} L_N^{\beta}$$

- L_R , L_N: Labour inputs for R and NR tasks (C computer capital)
- Computer capital and non-routine tasks are complementary
- Perfect substitution btw C and L_R (for postulates 1 and 2).
- Marginal productivity of NR tasks increases with an increase in L_R (3)

Workers' choice

- One worker may supply R or NR tasks.

$$E_i = [r_i, n_i]$$
$$L_i = [\lambda_i r_i, (1 - \lambda_i) n_i]\,; 0 \leq \lambda \ \leq 1$$

- This supply depends on the elasticity of relative wages

Equilibrium

- The assumption is that computers and R tasks are perfect substitutes. A decrease in the price of computers reduces the salary of R workers (not different from what's happening nowadays)

$$w_r = \rho$$

- The relative efficience for worker i between R and NR tasks:

$$\eta_i = \frac{n_i}{r_i} \qquad \text{in equilibrium} \qquad \eta * = \frac{w_R}{w_N}$$

Results

- $\frac{\partial ln\theta}{\partial ln\rho} = -\frac{1}{\beta}$
- $\theta \equiv \frac{C+g(\eta*)}{h(\eta*)}$
- An increase in the demand for routine tasks can be faced by
  - An increase in computer caputal
  - An increase in routine inputs
  - Combination of the two

Results

- ONLY THE FIRST HAPPENS. Increase in computer capital
- The relative salary of NR workers increases when the price of computers decreases:

$$\frac{\partial \ln(\frac{w_N}{w_R})}{\partial ln\rho} = -\frac{1}{\beta}$$

- The marginal worker will choose to supply NR tasks instead of R ones

Theoretical conclusions

- The monotonic decrease in the price of computers increases the marginal productivity of NR workers
- This leads to an shift in labour supply from R to NR workers
- This gap in the supply of R tasks is filled by computer capital that substitutes R workers

Theoretical conclusions

- Computer capital is adopted in particular when its price decreases
- This is key in those industries that are R task intensive
- Computer capital satisfies the demand for R task inputs
- An increase in computer capital increases NR inputs
- This happens in many industries and also in some occupations (economists, engineers, etc.)

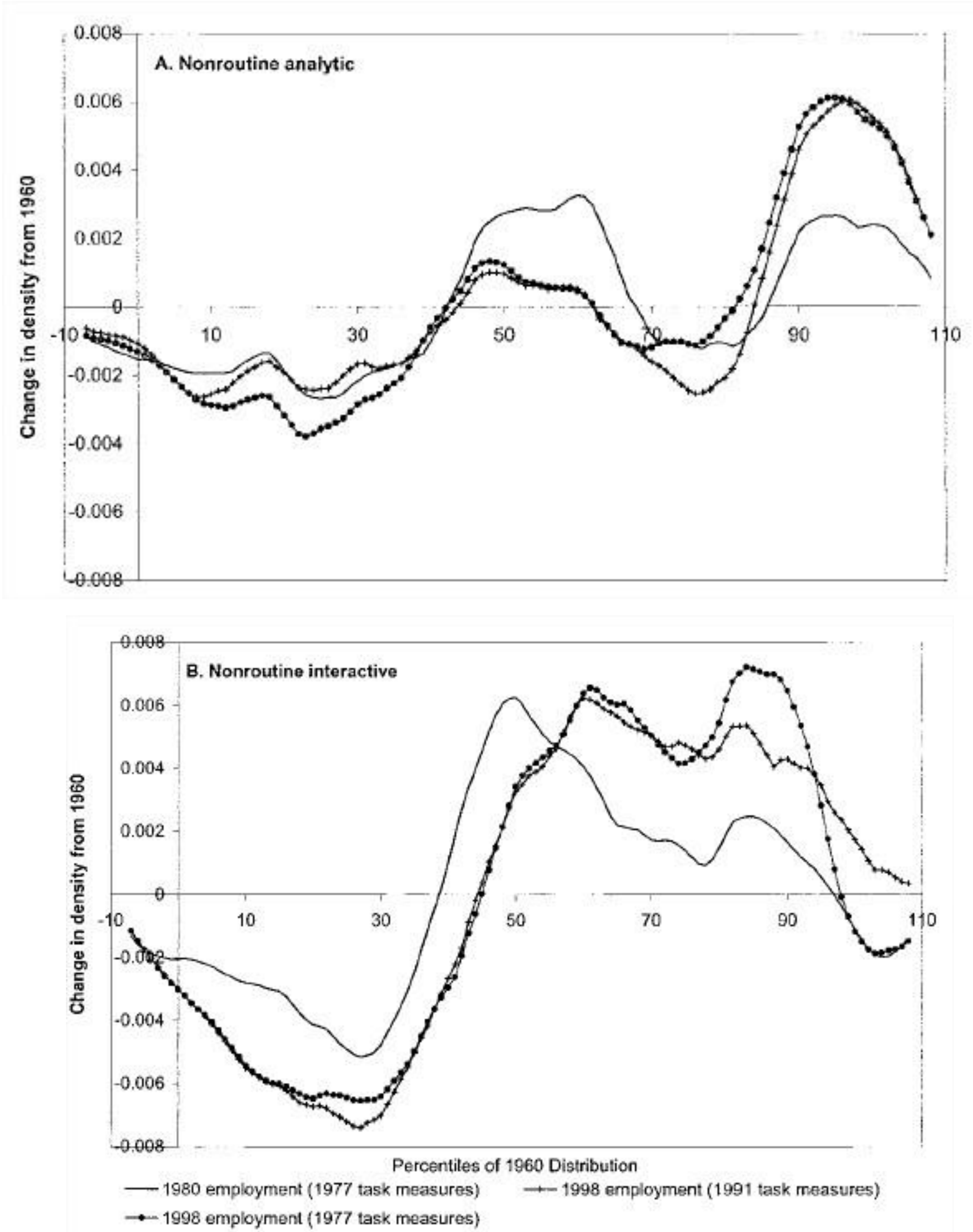
Empirical issues

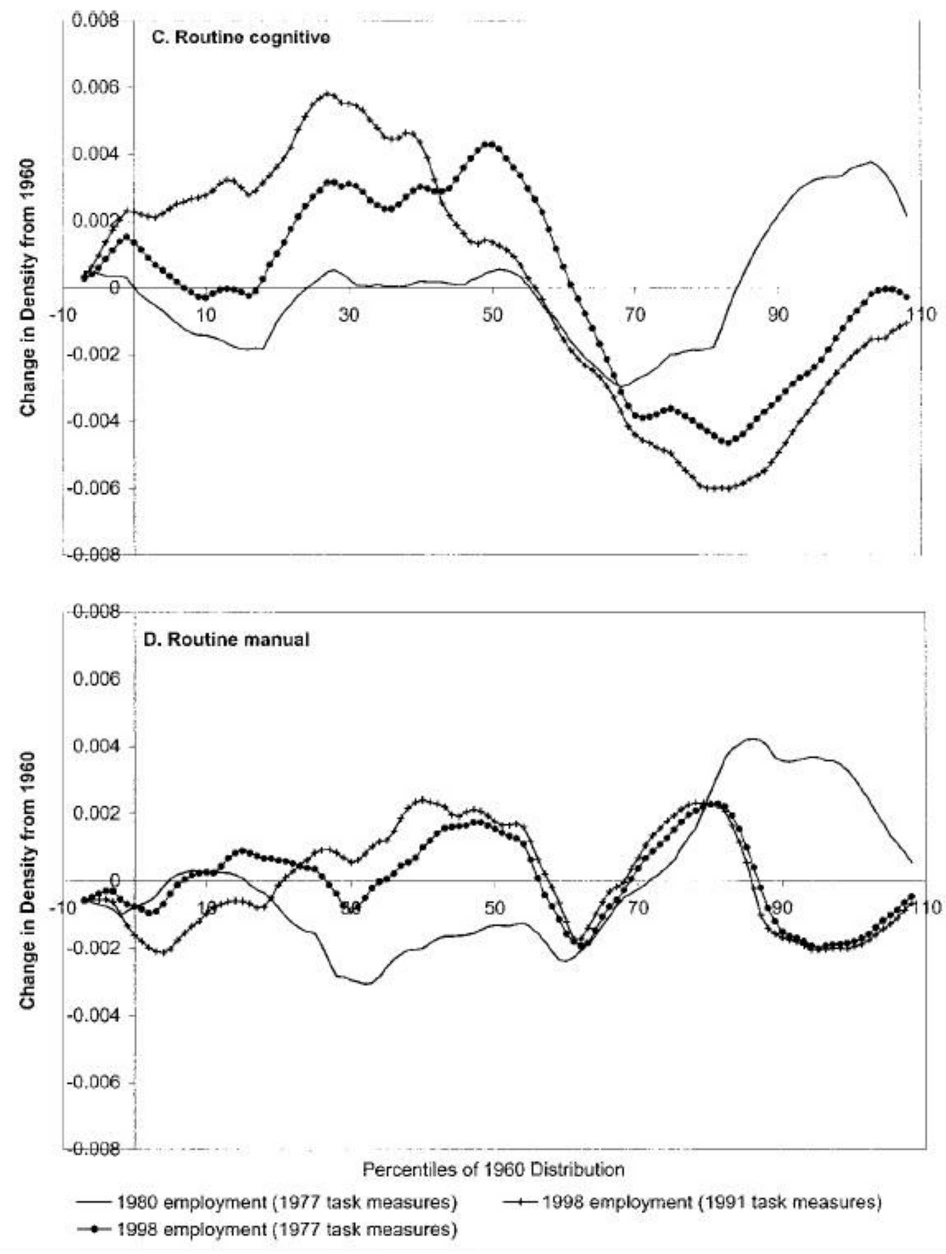
- The theoretical formalisation should be tested at the empirical level
- Problems:
  - How do we measure R and NR tasks?
  - What kind of data should we employ? Occupations? industries?

APPENDIX 1: DEFINITIONS OF TASK MEASURES FROM THE 1977 DICTIONARY OF OCCUPATIONAL TITLES

Variable	DOT definition	Task interpretation	Example tasks from *Handbook for Analyzing Jobs*
1. GED Math (MATH)	General educational development, mathematics	Measure of nonroutine analytic tasks	Lowest level: Adds and subtracts 2-digit numbers; performs operations with units such as cup, pint, and quart. Midlevel: Computes discount, interest, profit, and loss; inspects flat glass and compiles defect data based on samples to determine variances from acceptable quality limits. Highest level: Conducts and oversees analyses of aerodynamic and thermodynamic systems . . . to determine suitability of design for aircraft and missiles.
2. Direction, Control, Planning (DCP)	Adaptability to accepting responsibility for the direction, control, or planning of an activity	Measure of nonroutine interactive tasks	Plans and designs private residences, office buildings, factories, and other structures; applies principles of accounting to install and maintain operation of general accounting system; conducts prosecution in court proceedings . . . gathers and analyzes evidence, reviews pertinent decisions . . . appears against accused in court of law; commands fishing vessel crew engaged in catching fish and other marine life.
3. Set Limits, Tolerances, or Standards (STS)	Adaptability to situations requiring the precise attainment of set limits, tolerances, or standards	Measure of routine cognitive tasks	Operates a billing machine to transcribe from office records data; calculates degrees, minutes, and second of latitude and longitude, using standard navigation aids; measures dimensions of bottle, using gauges and micrometers to verify that setup of bottle-making conforms to manufacturing specifications; prepares and verifies voter lists from official registration records.
4. Finger Dexterity (FINGDEX)	Ability to move fingers, and manipulate small objects with fingers, rapidly or accurately	Measure of routine manual tasks	Mixes and bakes ingredients according to recipes; sews fasteners and decorative trimmings to articles; feeds tungsten filament wire coils into machine that mounts them to stems in electric light bulbs; operates tabulating machine that processes data from tabulating cards into printed records; packs agricultural produce such as bulbs, fruits, nuts, eggs, and vegetables for storage or shipment; attaches hands to faces of watches.
5. Eye Hand Foot Coordination (EYEHAND)	Ability to move the hand and foot coordinately with each other in accordance with visual stimuli	Measure of nonroutine manual tasks	Lowest level: Tends machine that crimps eyelets, grommets; next level: attends to beef cattle on stock ranch; drives bus to transport passengers; next level: pilots airplane to transport passengers; prunes and treats ornamental and shade trees; highest level: performs gymnastic feats of skill and balance.

Source: U. S. Department of Labor, Manpower Administration, *Handbook for Analyzing Jobs* (Washington, DC, 1972).


A. Nonroutine analytic
Change in density from 1960
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-10
10
30
50
70
90
110
B. Nonroutine interactive
Change in density from 1960
Percentiles of 1960 Distribution
1980 employment (1977 task measures)
1998 employment (1991 task measures)
1998 employment (1977 task measures)



C. Routine cognitive
D. Routine manual
Change in Density from 1960
Percentiles of 1960 Distribution
1980 employment (1977 task measures)
1998 employment (1991 task measures)
1998 employment (1977 task measures)

Appendix 2: Computerization and Industry Task Input, 1960–1998: Using Composite Task Measures

Dependent Variable: 10 × Annual within-Industry Change in Task Input, Measured in Percentiles of 1960 Task Distribution

		1. 1990–1998	2. 1980–1990	3. 1970–1980	4. 1960–1970
A. Δ Nonroutine analytic	Δ Computer use 1984–1997	8.21	12.09	6.50	8.57
		(4.55)	(4.55)	(4.21)	(5.74)
	Intercept	0.64	−0.67	0.07	−0.07
		(0.96)	(0.94)	(0.86)	(1.14)
	R^2	0.02	0.05	0.02	0.02
	Weighted mean Δ	2.26	1.67	1.32	1.51
B. Δ Nonroutine interactive	Δ Computer use 1984–1997	9.83	9.93	5.67	10.45
		(4.39)	(4.74)	(3.47)	(5.00)
	Intercept	0.54	0.53	1.42	0.00
		(0.92)	(0.98)	(0.71)	(1.00)
	R^2	0.04	0.03	0.02	0.03
	Weighted mean Δ	2.48	2.45	2.51	1.93
C. Δ Routine cognitive	Δ Computer use 1984–1997	−13.40	−4.59	−4.76	−7.02
		(4.44)	(5.58)	(3.70)	(4.75)
	Intercept	0.23	−0.39	0.56	−0.05
		(0.94)	(1.16)	(0.76)	(0.95)
	R^2	0.06	0.00	0.01	0.02
	Weighted mean Δ	−2.41	−1.28	−0.35	−1.35
D. Δ Routine manual	Δ Computer use 1984–1997	−23.17	−15.27	−13.25	3.98
		(6.99)	(6.86)	(5.34)	(4.13)
	Intercept	−0.52	−0.80	1.97	1.35
		(1.47)	(1.42)	(1.09)	(0.82)
	R^2	0.07	0.03	0.04	0.01
	Weighted mean Δ	−5.09	−3.76	−0.56	2.09

TABLE V

COMPUTERIZATION AND INDUSTRY TASK INPUT 1980–1998: OVERALL AND BY EDUCATION GROUP

DEPENDENT VARIABLE: 10 × ANNUAL CHANGE IN QUANTILES OF TASK MEASURE, MEASURED IN PERCENTILES OF 1960 TASK DISTRIBUTION

	1. Δ Nonroutine analytic	2. Δ Nonroutine interactive	3. Δ Routine cognitive	4. Δ Routine manual
	A. Aggregate within-industry change			
Δ Computer use	12.95	15.97	−15.84	−14.32
1984–1997	(3.68)	(4.32)	(4.73)	(4.73)
Intercept	−0.33	1.27	0.38	0.54
	(0.77)	(0.90)	(0.99)	(0.99)
Weighted mean task Δ	2.20	4.39	−2.71	−2.25
	B. Within industry: High school dropouts			
Δ Computer use	4.64	11.92	−2.64	−8.85
1984–1997	(6.07)	(8.73)	(7.95)	(6.76)
Intercept	−2.51	−4.39	0.02	1.11
	(1.26)	(1.82)	(1.66)	(1.41)
Weighted mean task Δ	−1.61	−2.07	−0.49	−0.62
	C. Within industry: High school graduates			
Δ Computer use	0.04	13.49	−28.18	−25.50
1984–1997	(4.17)	(5.40)	(6.13)	(6.05)
Intercept	−1.49	1.07	1.55	0.48
	(0.87)	(1.13)	(1.28)	(1.26)
Weighted mean task Δ	−1.48	3.70	−3.95	−4.49
	D. Within industry: Some college			
Δ Computer use	7.95	18.14	−15.68	−17.77
1984–1997	(5.03)	(5.54)	(5.27)	(5.61)
Intercept	−1.88	−0.58	0.35	1.39
	(1.05)	(1.15)	(1.10)	(1.17)
Weighted mean task Δ	−0.33	2.96	−2.71	−2.08
	E. Within industry: College graduates			
Δ Computer use	1.61	5.57	−0.78	−4.46
1984–1997	(3.42)	(3.35)	(4.85)	(5.70)
Intercept	0.25	0.10	−0.96	−0.12
	(0.71)	(0.70)	(1.01)	(1.19)
Weighted mean task Δ	0.57	2.22	−1.48	−1.98
	F. Decomposition into within and between education group components			
Explained task Δ	2.52	3.11	−3.09	−2.79
Within educ groups (%)	23.7	77.9	91.7	111.1
Between educ groups (%)	76.3	22.1	8.3	−11.1

TABLE IV

COMPUTER INVESTMENT, CAPITAL INTENSITY, AND TASK INPUT IN THREE-DIGIT INDUSTRIES 1960–1998: STACKED FIRST-DIFFERENCE ESTIMATES

DEPENDENT VARIABLE: 10 × ANNUAL CHANGE IN QUANTILES OF TASK MEASURE, MEASURED IN PERCENTILES OF 1960 TASK DISTRIBUTION

	A. Δ Nonroutine analytic		B. Δ Nonroutine interactive		C. Δ Routine cognitive		D. Δ Routine manual	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Log(*CI*/*L*)	6.65	6.76	11.59	10.03	−8.27	−8.30	−9.11	−8.20
	(4.13)	(3.97)	(3.21)	(3.31)	(3.63)	(3.26)	(2.57)	(2.29)
	[6.36]	[5.90]	[3.97]	[4.50]	[4.74]	[3.76]	[3.27]	[2.86]
Log(*KI*/*L*)	1.22		−3.41		−2.93		−2.42	
	(4.36)		(4.58)		(4.76)		(3.95)	
	[6.36]		[4.45]		[7.31]		[5.87]	
Δ Log(*K*/*L*)		0.24		3.01		−1.32		−3.89
		(2.35)		(2.24)		(2.12)		(1.92)
		[2.36]		[2.19]		[2.18]		[2.38]
1970–1980 dummy	−0.64	−0.54	1.38	2.49	−0.32	−0.84	0.68	−0.80
	(1.08)	(1.29)	(1.50)	(1.62)	(1.31)	(1.58)	(0.96)	(1.17)
	[1.02]	[1.23]	[2.07]	[2.12]	[1.13]	[0.93]	[0.94]	[1.03]
1980–1990 dummy	−0.34	−0.25	0.58	1.83	−1.62	−2.14	−1.32	−2.90
	(1.57)	(1.60)	(1.81)	(1.70)	(1.56)	(1.86)	(1.11)	(1.38)
	[1.43]	[1.67]	[1.58]	[1.46]	[1.33]	[1.35]	[0.86]	[1.07]
1990–1998 dummy	−1.19	−1.13	−1.91	−0.90	−1.33	−1.71	−1.15	−2.36
	(1.55)	(1.62)	(1.83)	(1.70)	(1.66)	(1.64)	(1.32)	(1.47)
	[1.77]	[1.93]	[1.85]	[1.88]	[1.93]	[1.63]	[0.95]	[1.13]
Intercept	8.89	8.23	12.40	11.30	−9.29	−7.09	−9.62	−5.55
	(4.08)	(4.42)	(4.25)	(3.59)	(4.12)	(3.63)	(3.14)	(2.67)
	[5.45]	[6.38]	[4.76]	[4.80]	[4.48]	[4.36]	[3.75]	[3.30]
R^2	0.06	0.06	0.11	0.12	0.14	0.14	0.20	0.21

	Weighted mean of dependent variable			
1960–1970	1.16	1.74	1.30	1.63
1970–1980	1.23	4.59	−0.20	0.98
1980–1990	2.07	4.69	−2.05	−1.74
1990–1998	2.15	3.76	−3.03	−2.82

Is this the end of the story?

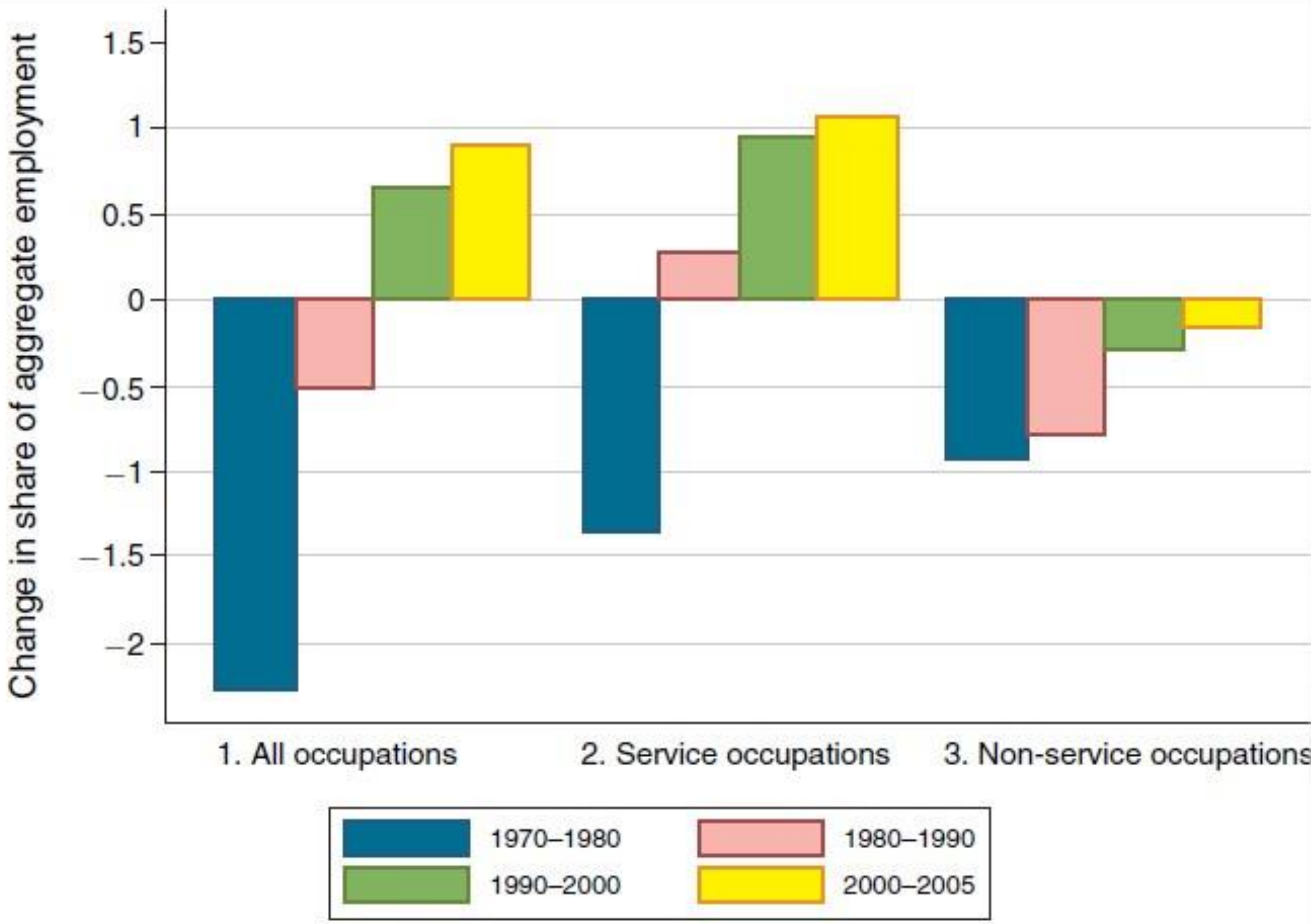
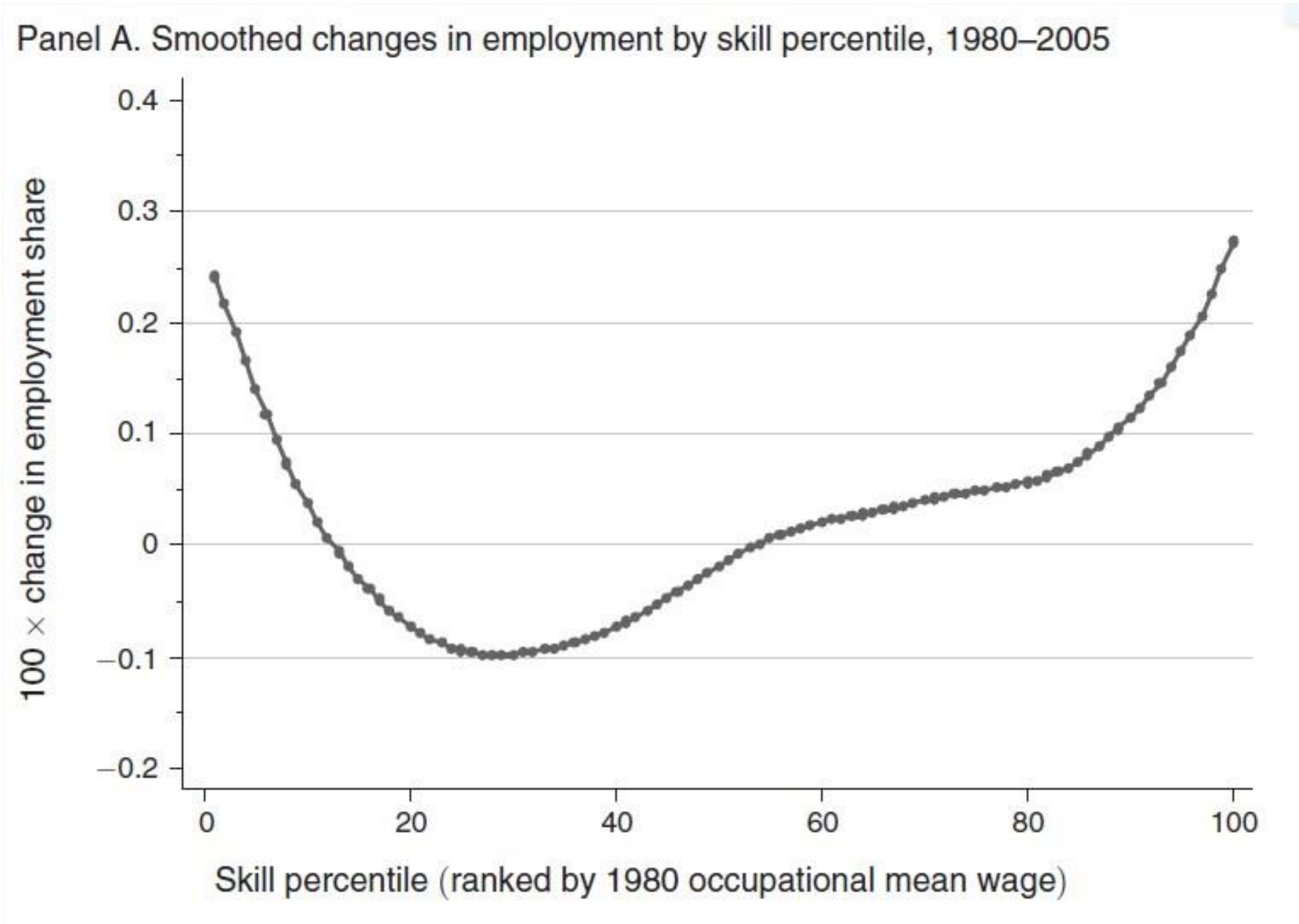


Figure 3. Change in Aggregate Employment Share by Decade 1970 through 2005 in Occupations Comprising the Lowest Skill Quintile of Employment in 1980

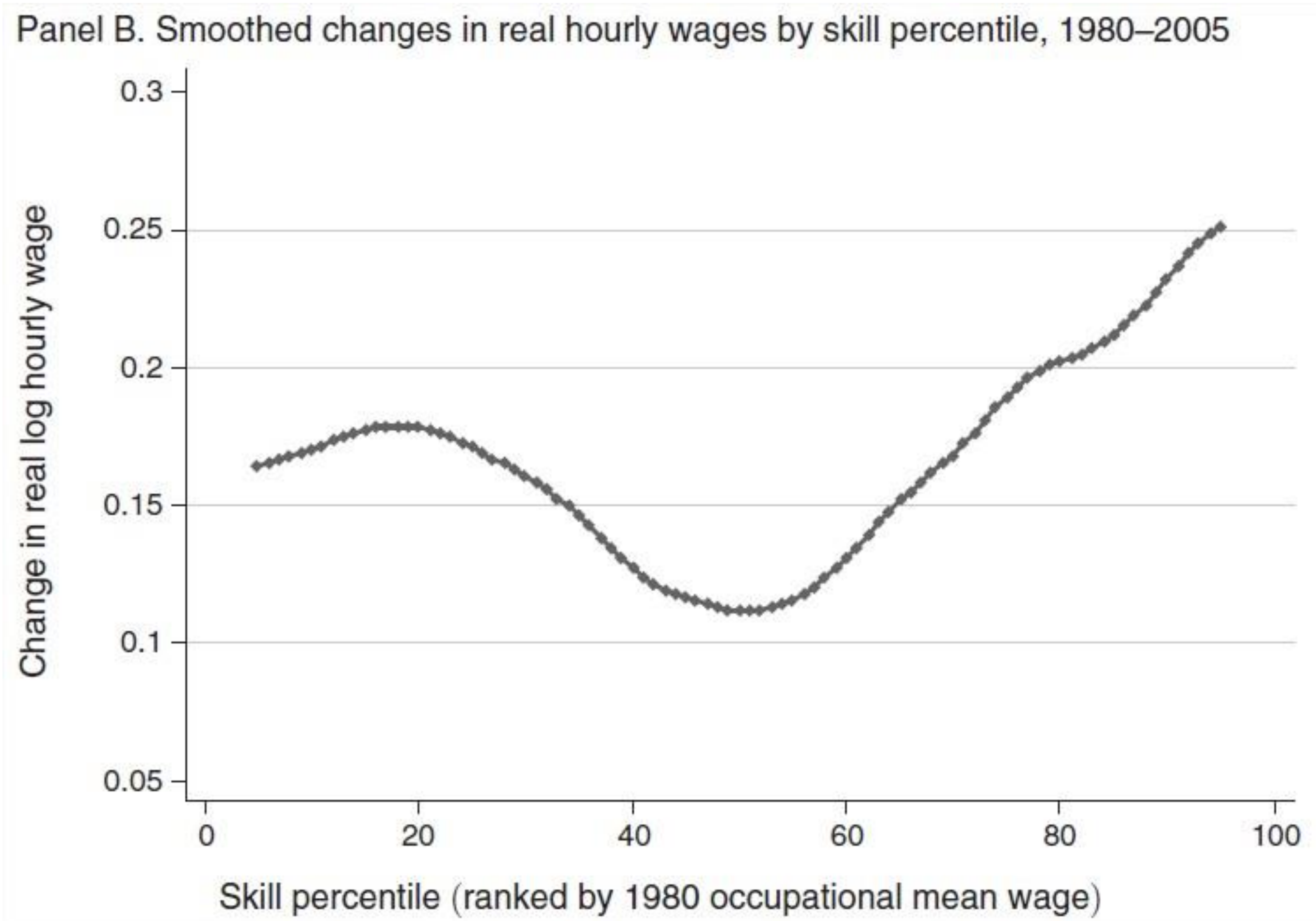
Autor and Dorn, 2013

Polarisation



Autor and Dorn, 2013

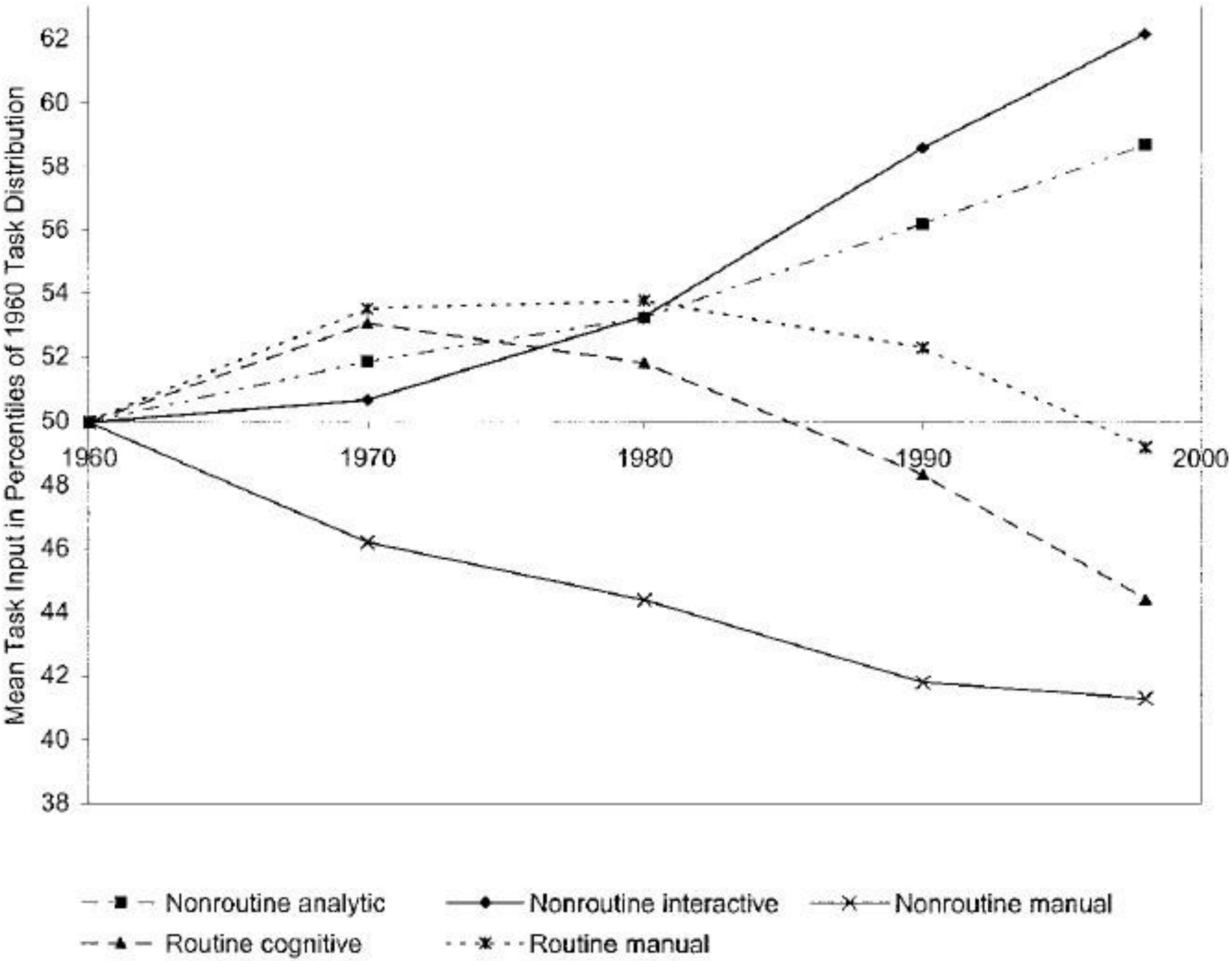
Polarisation



Autor and Dorn, 2013

Routine biased TC (Autor et al. 2003)

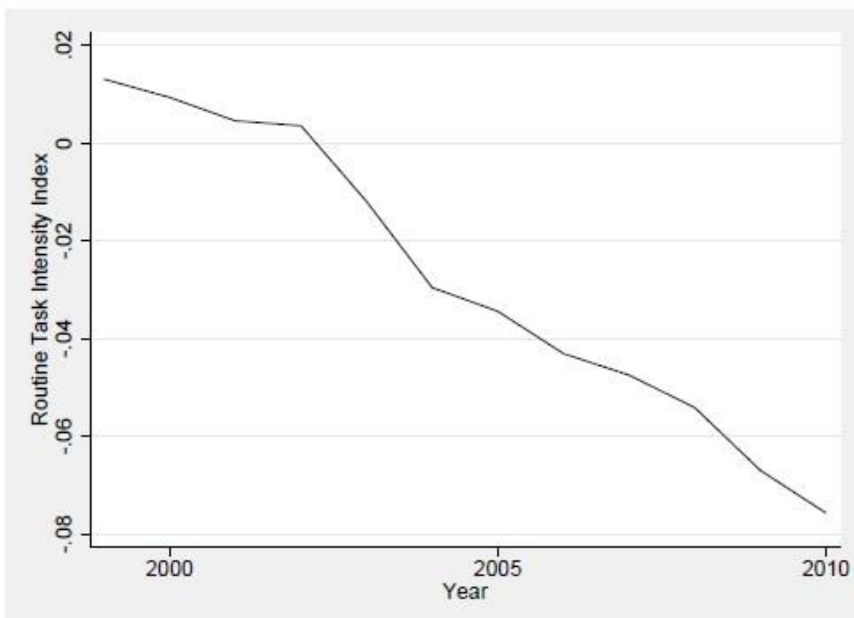
- Autor et al. (2003) have shown that ICT replaces human labor in routine tasks, while complementing it in many non-routine tasks
- Several studies show that changes in employment structures are similar across a large set of developed economies,
- consistent with the RBTC hypothesis which predicts a relative decrease in labor demand for jobs intense in routine tasks


Mean Task Input in Percentiles of 1960 Task Distribution
62
60
58
56
54
52
50
48
46
44
42
40
38
1960
1970
1980
1990
2000
Nonroutine analytic
Nonroutine interactive
Nonroutine manual
Routine cognitive
Routine manual

Europe

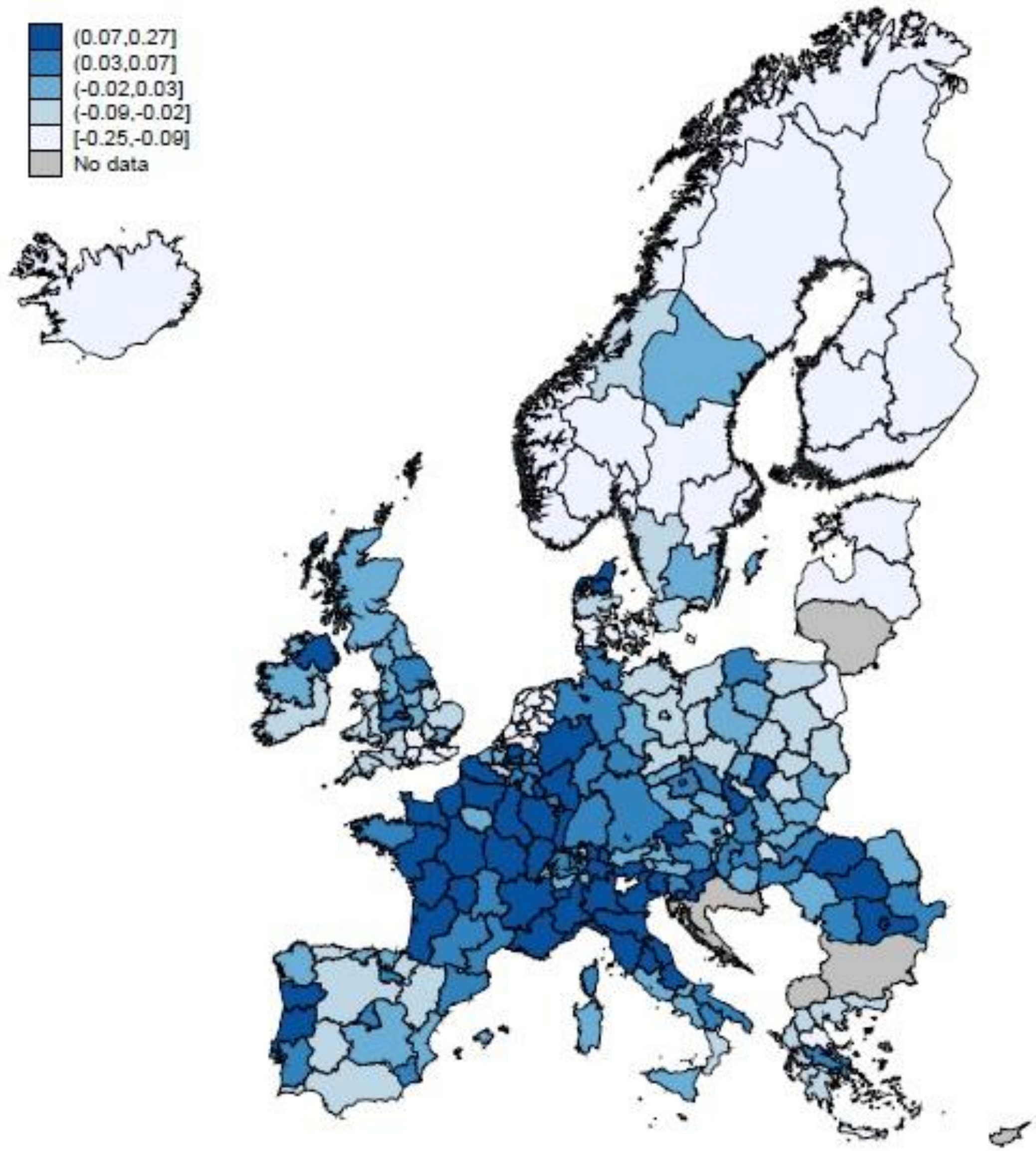
- the composition of aggregate employment has indeed been shifting away from routine tasks

Figure 1: Routine Task Intensity of European Employment, 1999-2010



Gregory et al., 2015

Figure 2: Spatial Distribution of Routine Task Intensity Across European Regions, 1999



Gregory et al., 2015

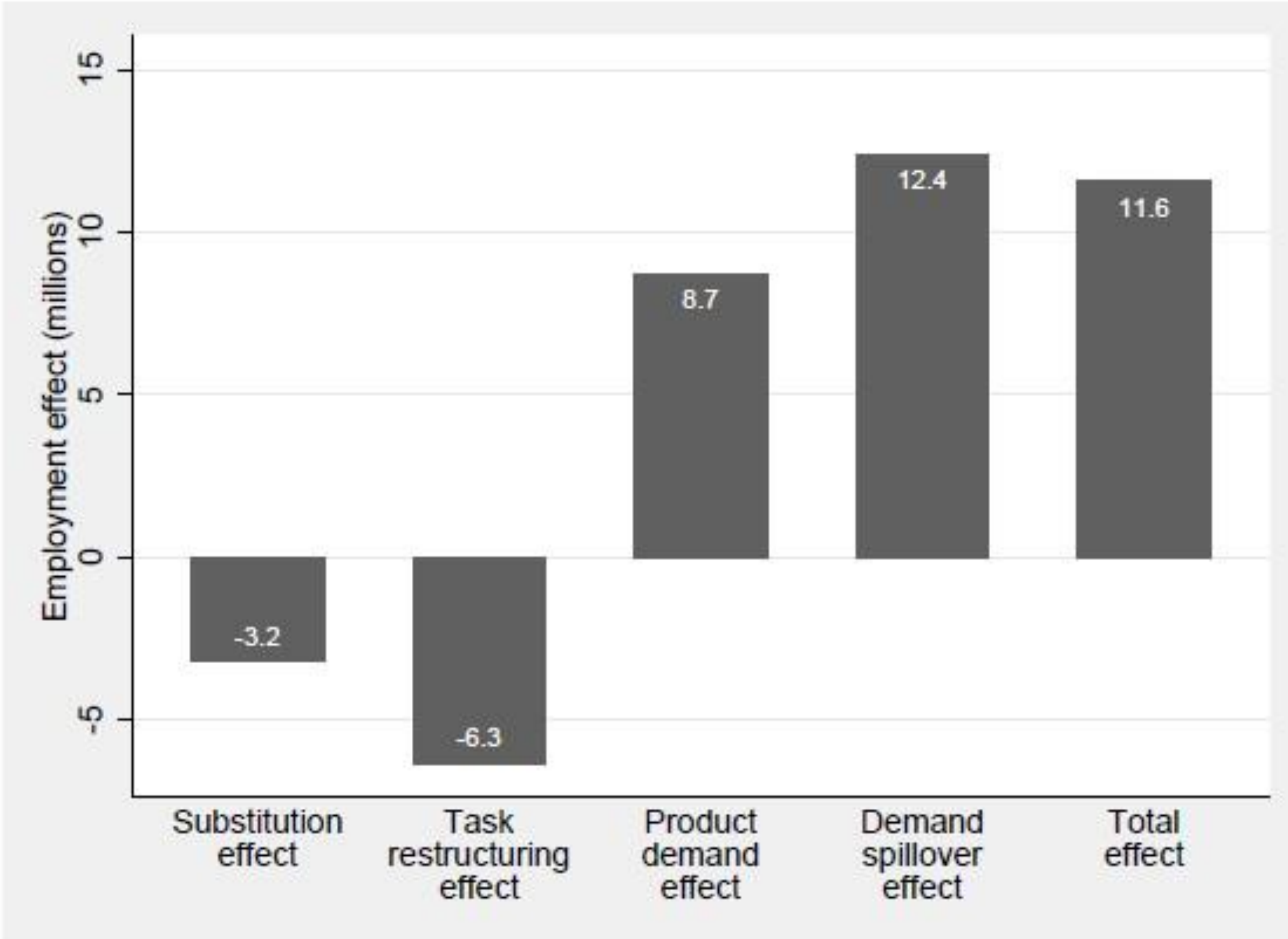
Table 2: Occupational Routine Task Intensity (RTI) index

ISCO	Occupation	RTI
1	Legislators, senior officials and managers	-0.94
2	Professionals	-1.01
3	Technicians and associate professionals	-0.28
4	Clerks	2.01
5	Service workers and shop and market sales workers	-0.75
7	Craft and related trades workers	0.38
8	Plant and machine operators and assemblers	0.48
9	Elementary occupations	0.10

Notes: RTI standardized to have a zero mean and unit standard deviation across occupations. Armed forces (ISCO 6) and farming professionals (ISCO 0) have been excluded from the dataset.

Gregory et al., 2015

Figure 6: Predicted European Employment Change, 1999-2010



Gregory et al., 2015