

Has Technology Changed the **Task Content** of Production?

Daron Acemoglu
MIT

Pascual Restrepo
Boston University

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Anemic Growth of US Labor Demand from 1987 to 2017



► Can technology account for the slowdown?

Technology Matters! But in a Very Specific Way...

- ▶ Opening the **black box** of technology:
 - ▶ techs that **change the allocation** of tasks between capital and labor
e.g: automation vs. creation of new tasks
 - ▶ techs that make labor or capital **more productive at tasks they already perform**
e.g: factor-augmenting technologies
- ▶ **Two takeaways:**
 - ▶ Theory: technologies that change task content of production have different impact on productivity and labor demand
 - ▶ Empirics: shift to faster automation but slower creation of new tasks

Agenda

1. Task framework and the role of the task content of production.
2. Multi-sector model that we use to connect with data and historical examples.
3. Labor demand decomposition, 1947-1987.
4. Labor demand decomposition, 1987-2017.
5. Correlates of change in task content across industries.
6. Concluding remarks.

1. Task framework and the role of the task content of production.

Thinking in Terms of Tasks: Motivation

- ▶ Automation in history: machines and computers used to substitute for human labor in a widening range of tasks:
 1. horse-powered reapers, harvesters, and threshing machines replaced manual labor
 2. machine tools replaced labor-intensive artisan techniques
 3. industrial robotics automated welding, machining, assembly, and packaging
 4. software automated routine tasks performed by white-collar workers
- ▶ But at the same time, new tasks in which labor has a comparative advantage.

Thinking in Terms of Tasks: Motivation

- ▶ Hard to map to canonical production function:

$$Y = F(A_L L, A_K K).$$

- ▶ Root of the problem:
 - ▶ task services are the units of production
 - ▶ L and K are inputs that provide task services
 - ▶ canonical model abstracts from allocation of tasks to factors
- ▶ Once we write $F(A_L L, A_K K)$
 - ▶ allocation of tasks to factors unchanged
 - ▶ or changes as capital (labor) becomes *more productive at all tasks*

Thinking in Terms of Tasks: Motivation

- ▶ Examples show technologies other than $\{A_L, A_K\}$ change allocation of tasks:
 - ▶ capital outperforms labor in a few tasks and industries
 - ▶ it becomes feasible to use capital at certain tasks
- ▶ We need to keep track of allocation—task content Γ —and understand implications

$$Y = F(A_L L, A_K K; \Gamma).$$

- ▶ Start from micro-foundations and then aggregate.

Thinking in Terms of Tasks: Framework

$$Y = \left(\int_{N-1}^N \mathcal{Y}(z)^{\frac{\sigma-1}{\sigma}} dz \right)^{\frac{\sigma}{\sigma-1}}$$

Output Task services Elast of substitution

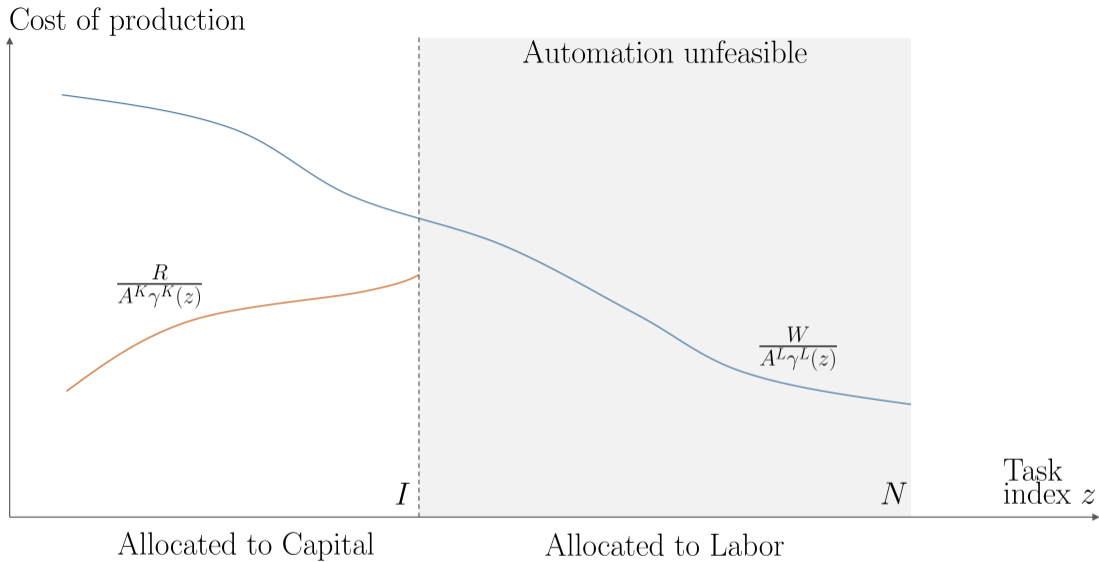
- ▶ Tasks can be produced using capital or labor:

$$\mathcal{Y}(z) = \begin{cases} A^L \gamma^L(z) \ell(z) + A^K \gamma^K(z) k(z) & \text{if } z \in [N-1, I] \\ A^L \gamma^L(z) \ell(z) & \text{if } z \in (I, N]. \end{cases}$$

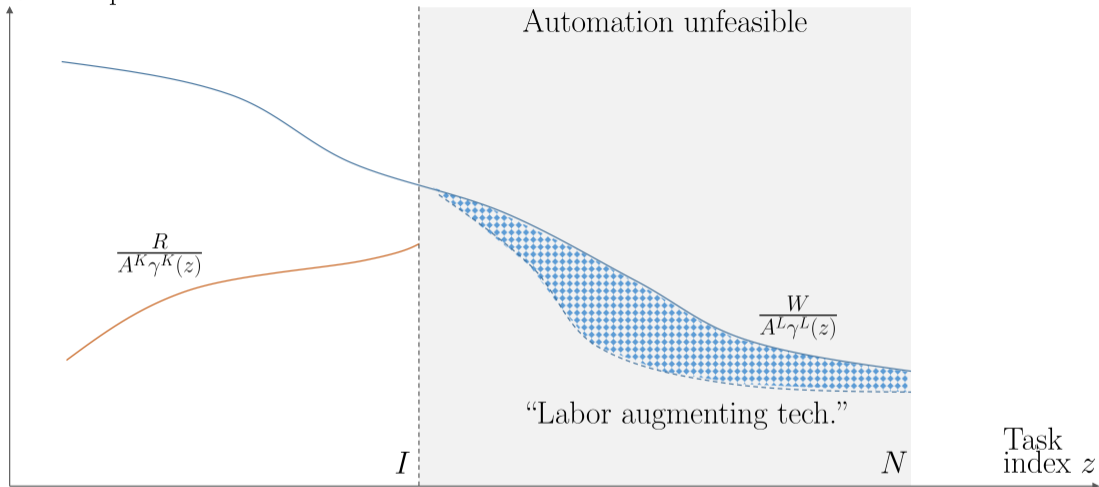
Feasible to automate

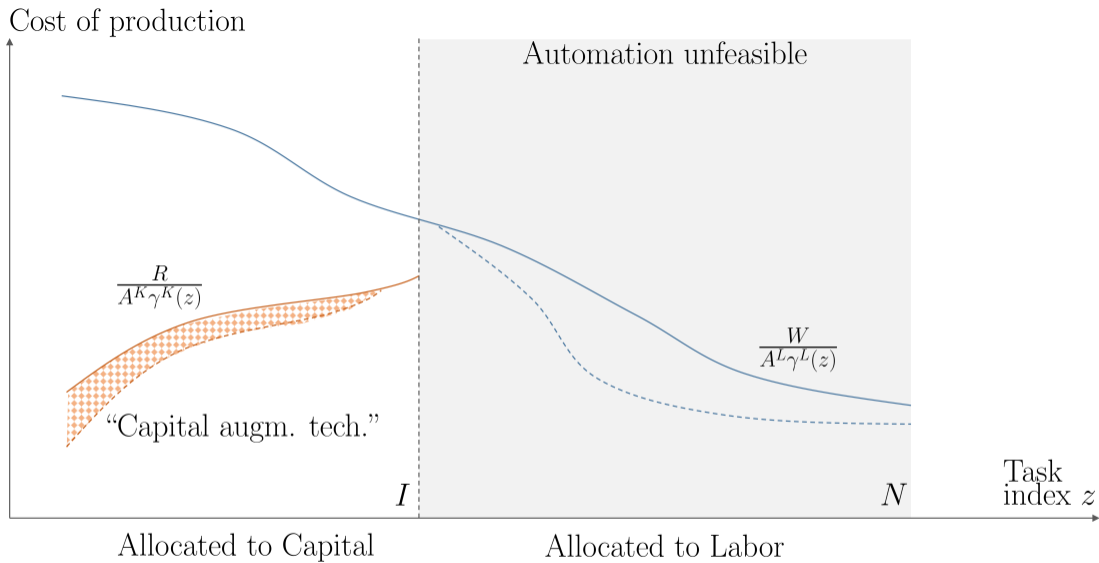
New tasks

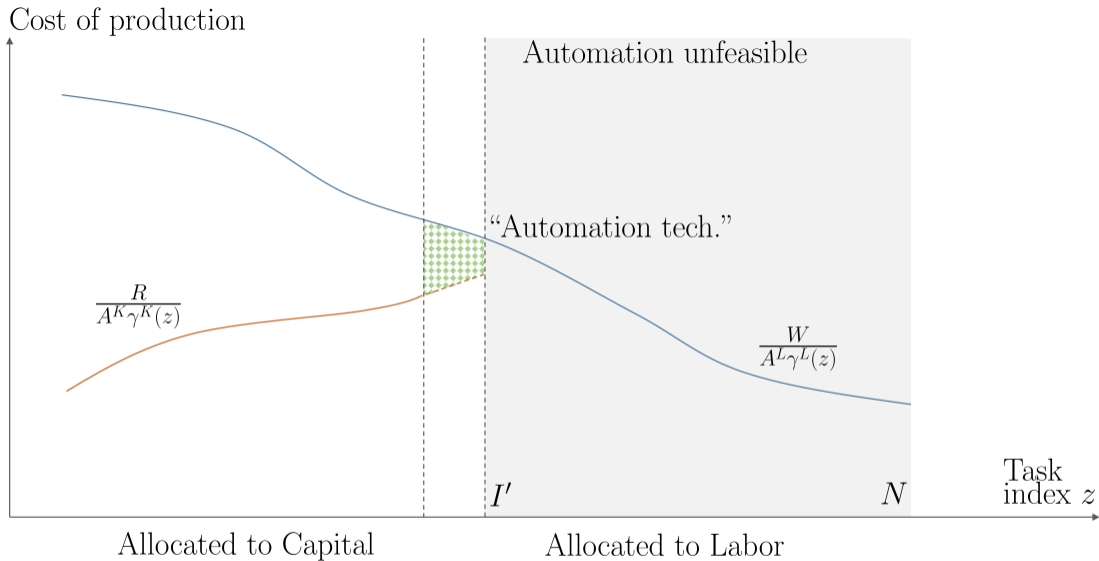
- ▶ Comparative advantage: $\gamma^L(z)/\gamma^K(z)$ and $\gamma^L(z)$ increasing in z .

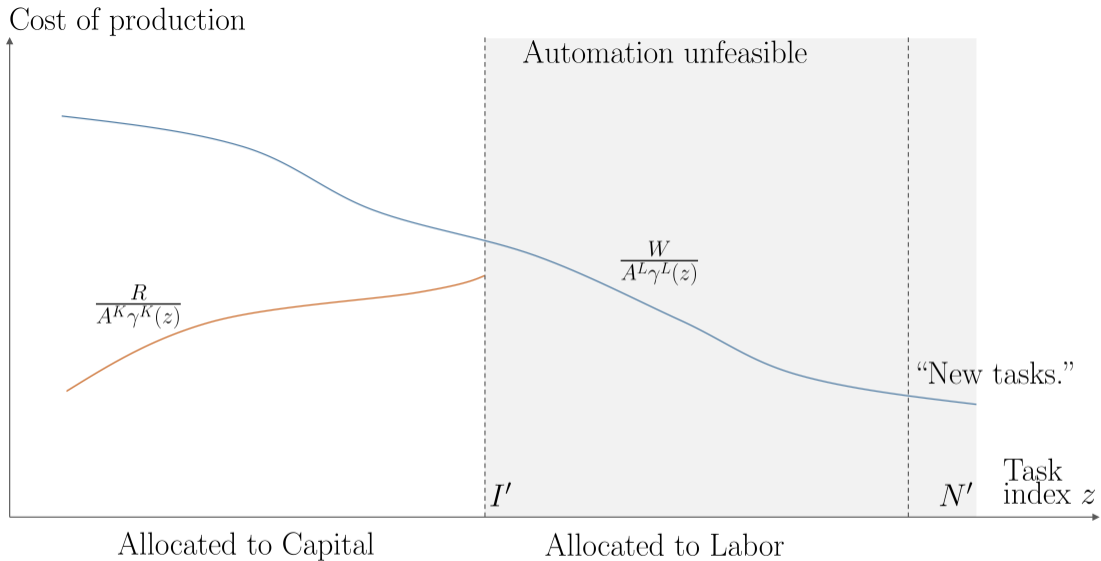


Cost of production









Thinking in Terms of Tasks: Framework

$$Y(L, K) = \left(\left(\int_{N-1}^I \gamma^K(z)^{\sigma-1} dz \right)^{\frac{1}{\sigma}} (A^K K)^{\frac{\sigma-1}{\sigma}} + \left(\int_I^N \gamma^L(z)^{\sigma-1} dz \right)^{\frac{1}{\sigma}} (A^L L)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- ▶ A^K, A^L summarize all forms of factor-augmenting technologies.
- ▶ I, N summarize role of automation and new tasks.
- ▶ The labor share is given by

$$s^L = \frac{\Gamma(N, I)(W/A^L)^{1-\sigma}}{(1 - \Gamma(N, I))(R/A^K)^{1-\sigma} + \Gamma(N, I)(W/A^L)^{1-\sigma}}$$

Task content $\Gamma = \frac{\int_I^N \gamma^L(z)^{\sigma-1} dz}{\int_{N-1}^I \gamma^K(z)^{\sigma-1} dz + \int_I^N \gamma^L(z)^{\sigma-1} dz}$

Task-price subs.

Thinking in Terms of Tasks: Labor Demand

$$WL = Y \times s^L$$

Output

Labor share

Wage bill as
measure of labor demand

The diagram illustrates the equation $WL = Y \times s^L$. Three arrows point from descriptive text to parts of the equation: one from 'Output' to Y , one from 'Labor share' to s^L , and one from 'Wage bill as measure of labor demand' to WL .

Automation and Labor Demand

$$\frac{\partial \ln WL}{\partial I} = \frac{1}{\sigma - 1} \left[\left(\frac{R}{A^K \gamma^K(I)} \right)^{1-\sigma} - \left(\frac{W}{A^L \gamma^L(I)} \right)^{1-\sigma} \right] \quad (\text{Productivity effect} > 0)$$
$$+ \frac{1}{\sigma} \frac{1 - s^L}{1 - \Gamma(N, I)} \frac{\partial \ln \Gamma(N, I)}{\partial I} \quad (\text{Displacement effect} < 0)$$

- ▶ Net effect depends on technology/context:
 - ▶ “so-so technologies,” large displacement effect and small productivity gains
 - ▶ “brilliant technologies,” large displacement effect and large productivity gains
- ▶ Modest productivity growth does not necessarily signal slowdown of automation.

New Tasks and Labor Demand

$$\frac{\partial \ln WL}{\partial N} = \frac{1}{\sigma - 1} \left[\left(\frac{W}{A^L \gamma^L(N)} \right)^{1-\sigma} - \left(\frac{R}{A^K \gamma^K(N-1)} \right)^{1-\sigma} \right] \quad (\text{Productivity effect} > 0)$$
$$+ \frac{1}{\sigma} \frac{1 - s^L}{1 - \Gamma(N, I)} \frac{\partial \ln \Gamma(N, I)}{\partial N} \quad (\text{Reinstatement effect} > 0)$$

- ▶ New tasks have sharp effect on productivity and labor demand.
- ▶ Especially when labor is abundant and wages low.

Factor-Augmenting Technologies and Labor Demand

$$\frac{\partial \ln WL}{\partial \ln A^L} = s^L \quad (\text{Productivity effect})$$
$$+ \frac{\sigma - 1}{\sigma} (1 - s^L) \quad (\text{Task-price substitution}),$$
$$\frac{\partial \ln WL}{\partial \ln A^K} = (1 - s^L) \quad (\text{Productivity effect})$$
$$+ \frac{1 - \sigma}{\sigma} (1 - s^L) \quad (\text{Task-price substitution}).$$

- ▶ No displacement or reinstatement effect; task content unchanged.
- ▶ Task-price subs effect small ($\sigma \approx 1$) relative to productivity effect:
 - ▶ affect labor demand through productivity
 - ▶ changes in labor share concur with huge productivity increases

2 Multi-sector model that we use to connect with data and historical examples.

Aggregate Labor Demand

Wage bill as \longrightarrow
measure of labor demand

$$\begin{aligned} WL &= \sum_i W_i L_i \\ &= \sum_i P_i Y_i \times s_i^L \\ &= Y \times \sum_i \chi_i \times s_i^L. \end{aligned}$$

GDP

Composition, $\frac{P_i Y_i}{Y}$

Labor share industry

Decomposing Labor Demand: Main Equation

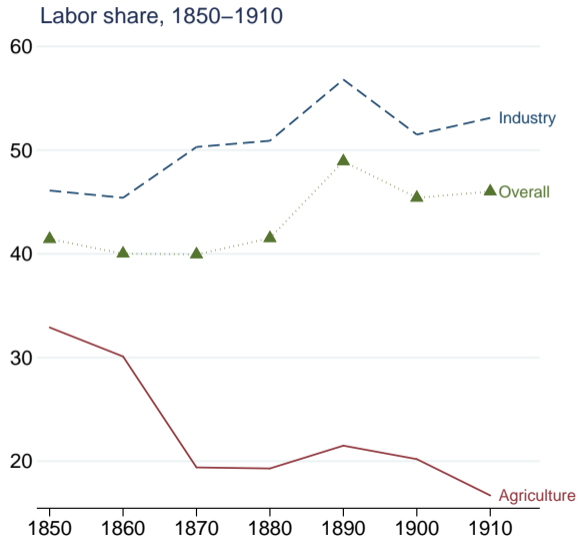
$$\begin{aligned}d \ln(WL) &= d \ln Y && \text{(Productivity effect)} \\ &+ \sum_{i \in \mathcal{I}} \left(\frac{s_i^L}{s^L} - 1 \right) d \chi_i && \text{(Composition effect)} \\ &+ \sum_{i \in \mathcal{I}} \ell_i \frac{1 - s_i^L}{1 - \Gamma_i} d \ln \Gamma_i && \text{(Change in task content)} \\ &+ \sum_{i \in \mathcal{I}} \ell_i (1 - \sigma) (1 - s_i^L) \left(d \ln \frac{W_i}{A_i^L} - d \ln \frac{R_i}{A_i^K} \right) && \text{(Task-price subs) .}\end{aligned}$$

- ▶ Productivity effect: aggregate expansion of output.
- ▶ Compositional effects: technology, preferences, trade.

Decomposing Labor Demand: An Example

Mechanization of agriculture:

- ▶ reduction in labor share within sector
- ▶ positive composition effect
- ▶ reinstatement within manufacturing
- ▶ large increase in labor demand



Taking Stock: Theory

- ▶ **Impact of technologies** on aggregate labor demand.
 1. all technologies generate labor demand by raising productivity—**prod effect**
 2. in addition, technologies change composition of economy—**comp effect**
 3. automation take task away from labor—**displacement effect**
 4. new tasks bring new tasks for labor—**reinstatement effect**

3 Labor demand decomposition, 1947-1987.

Decomposing Labor Demand: Implementation and Data

- ▶ Data: 48 industries for 1947-1987; 61 industries for 1987-2017.
- ▶ **Productivity** and **composition** effect directly from data.
- ▶ To quantify **task-price substitution**,

$$(1 - \sigma)(1 - s_{i,t}^L)[(\Delta \ln(W_{i,t}/R_{i,t}) - \Delta \ln(A_{i,t}^L/A_{i,t}^K))],$$

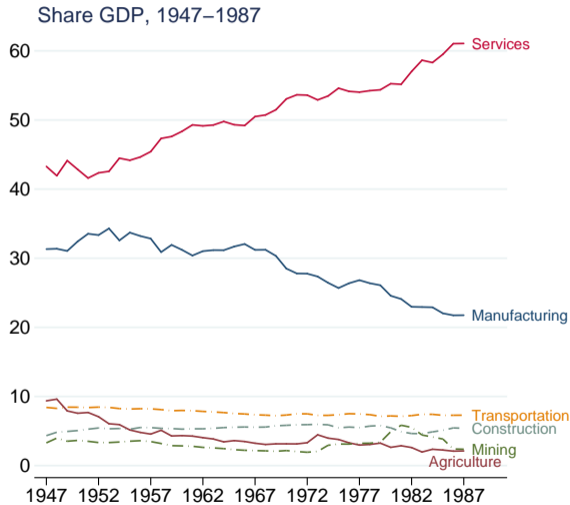
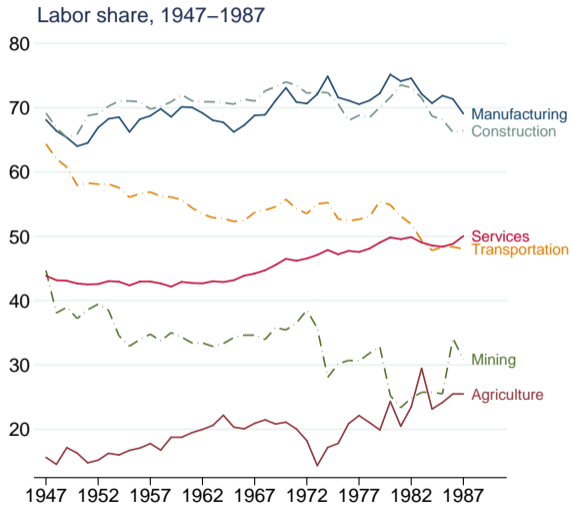
we take $\sigma = 0.8$ (Oberfield and Raval, 2014) and $d \ln A_i^L/A_i^K = 1.5\%$.

- ▶ We quantify **change in task content** as

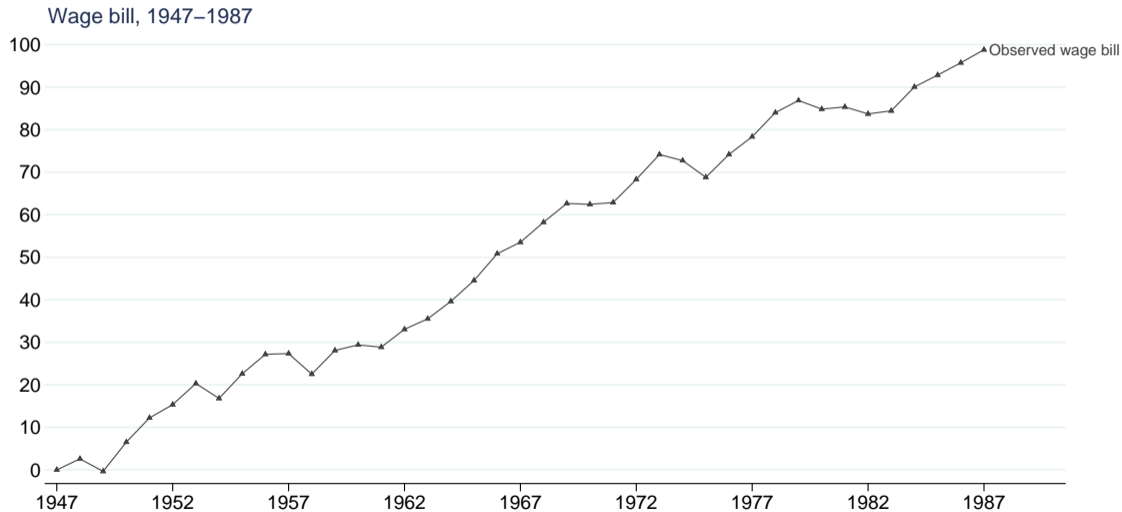
$$\frac{1 - s_i^L}{1 - \Gamma_i} d \ln \Gamma_i = \Delta \ln s_{i,t}^L - (1 - \sigma)(1 - s_{i,t}^L)[(\Delta \ln(W_{i,t}/R_{i,t}) - \Delta \ln(A_{i,t}^L/A_{i,t}^K))].$$

- ▶ Labor demand and output normalized by population.

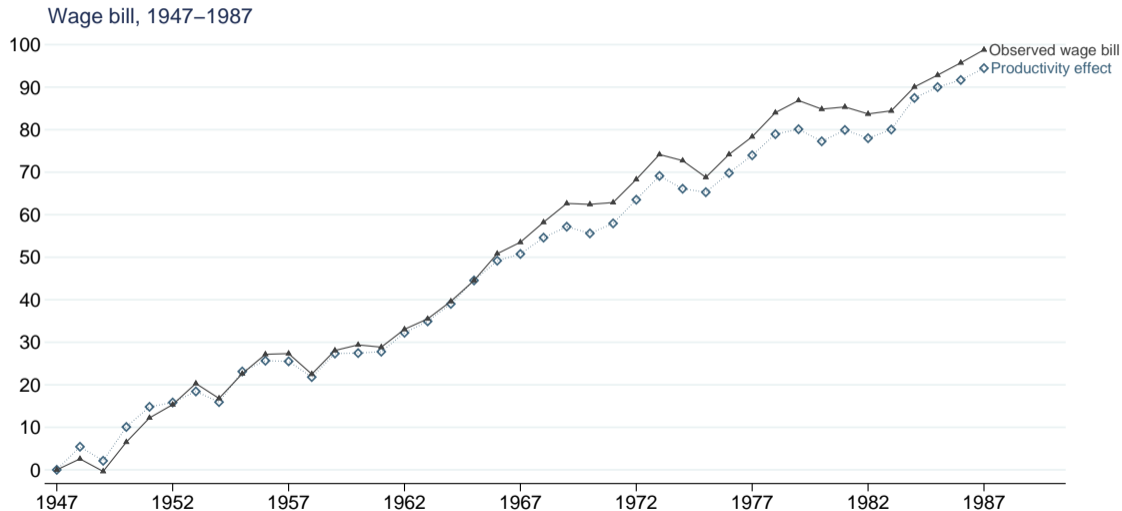
Decomposing Labor Demand: Raw data, 1947-1987



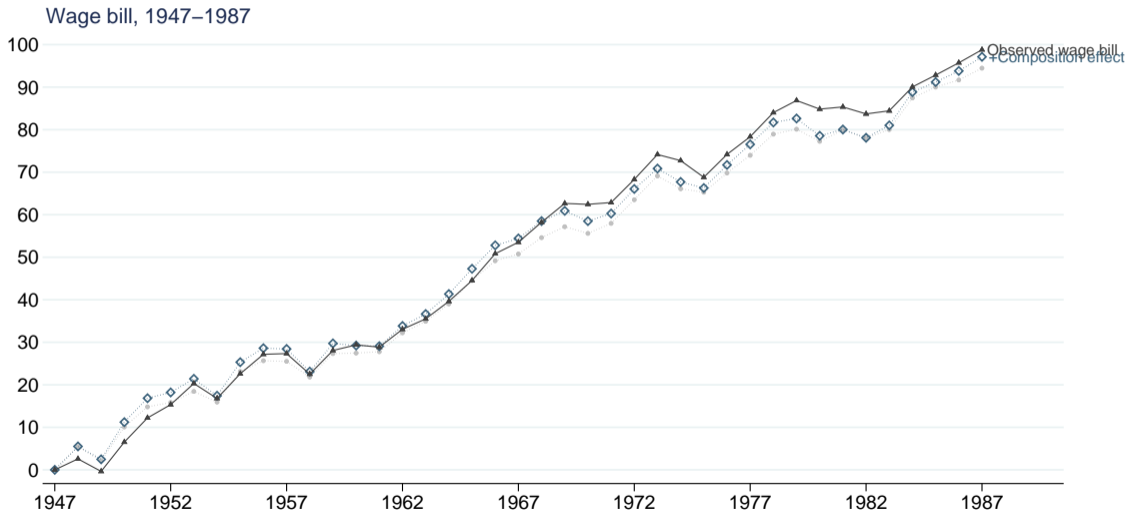
Decomposing Labor Demand: Decomposition, 1947-1987



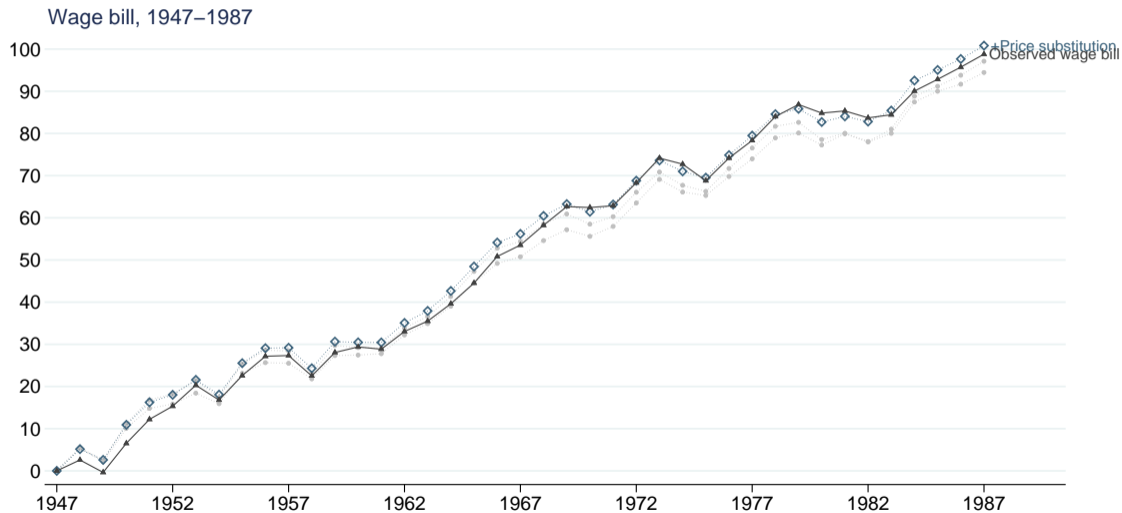
Decomposing Labor Demand: Decomposition, 1947-1987



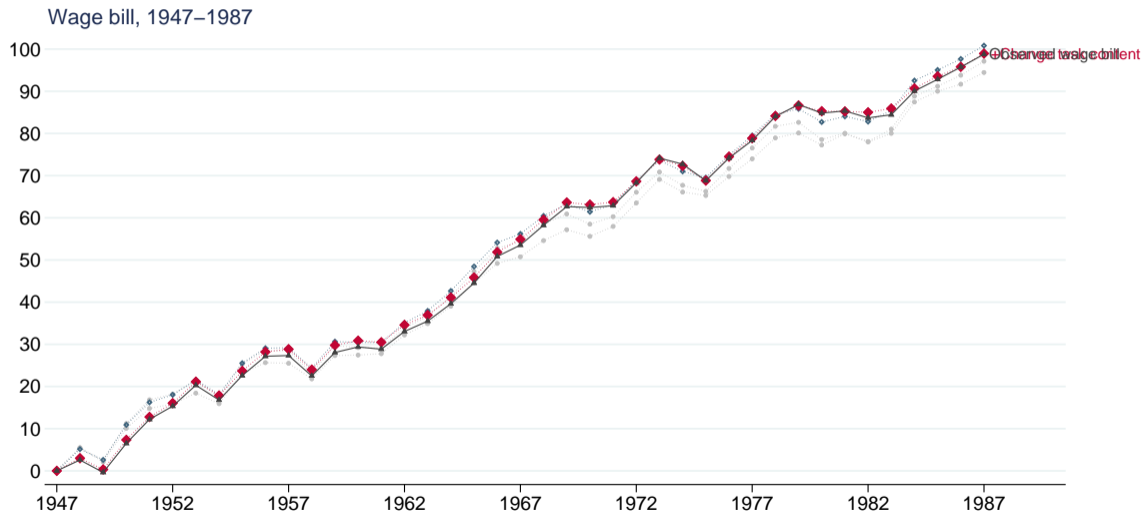
Decomposing Labor Demand: Decomposition, 1947-1987



Decomposing Labor Demand: Decomposition, 1947-1987



Decomposing Labor Demand: Decomposition, 1947-1987



Decomposing Labor Demand: Displacement and Reinstatement

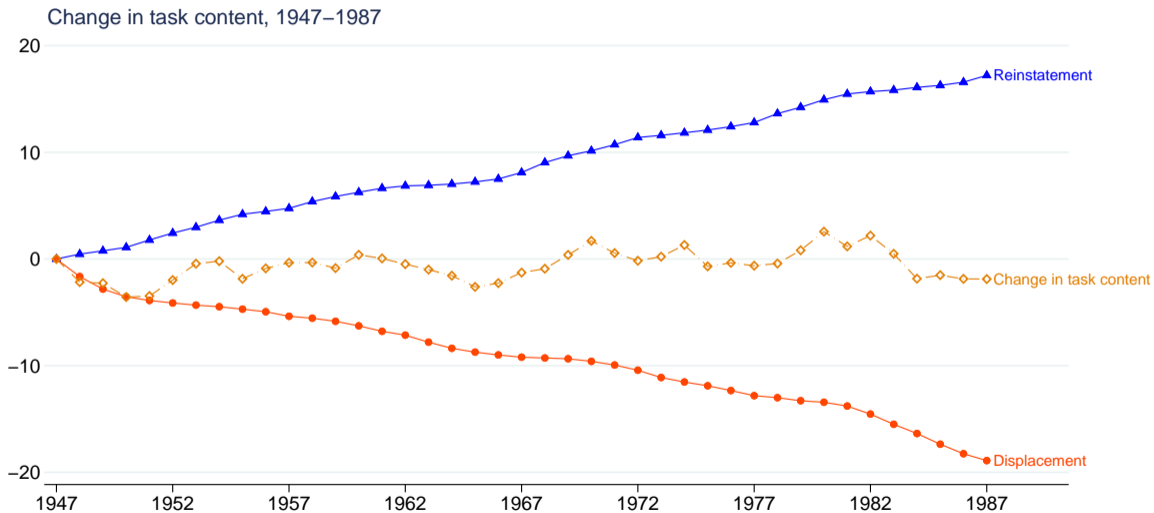
- ▶ Two assumptions:
 1. no technological regress.
 2. over five-year periods, changes in task content in industry driven by either automation or new tasks, but not both.
- ▶ Estimates:

$$\text{Displacement}_t = \sum_{i \in \mathcal{I}} \ell_{i,t} \min \left\{ 0, \frac{1}{5} \sum_{\tau=t-2}^{t+2} \text{Change in task content}_{i,\tau} \right\}$$

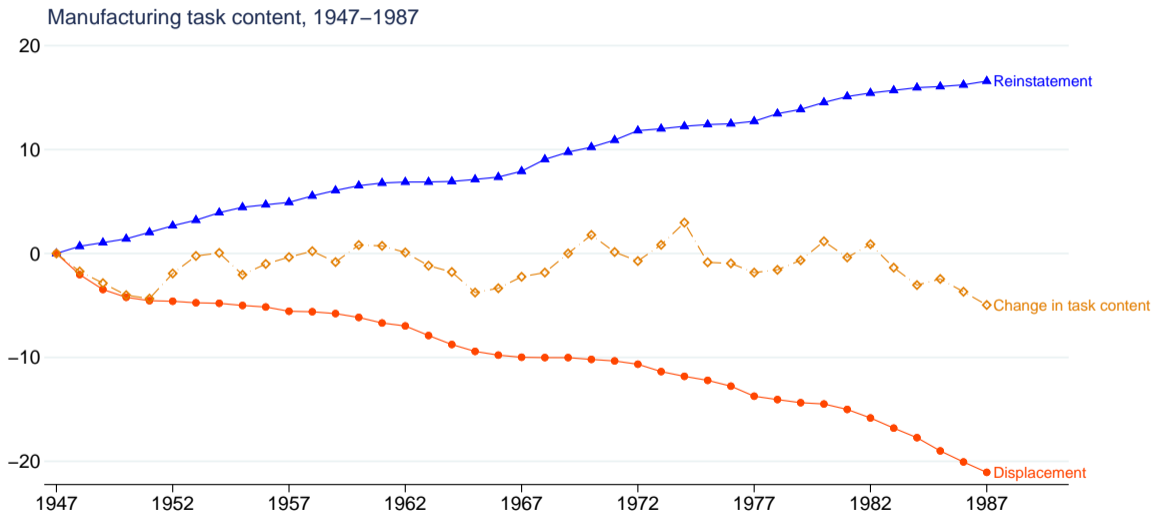
$$\text{Reinstatement}_t = \sum_{i \in \mathcal{I}} \ell_{i,t} \max \left\{ 0, \frac{1}{5} \sum_{\tau=t-2}^{t+2} \text{Change in task content}_{i,\tau} \right\}.$$

- ▶ Lower bounds if simultaneous automation and creation of new tasks.

Displacement and Reinstatement, 1947-1987



Displacement and Reinstatement, Manufacturing 1947-1987

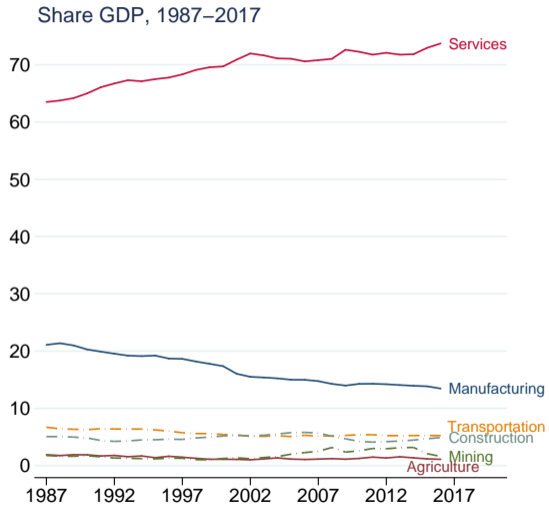
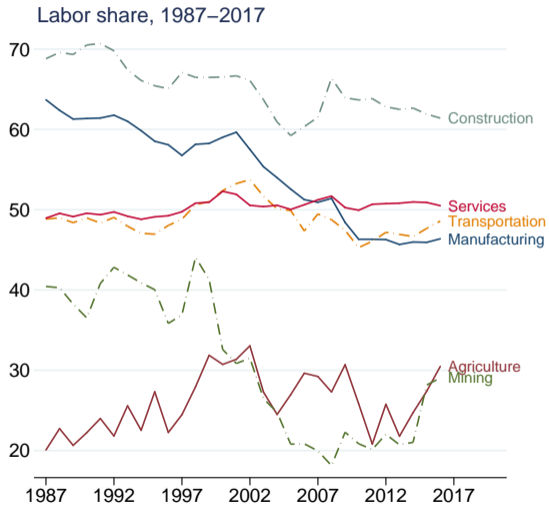


Decomposing Labor Demand: Taking stock, 1947-1987

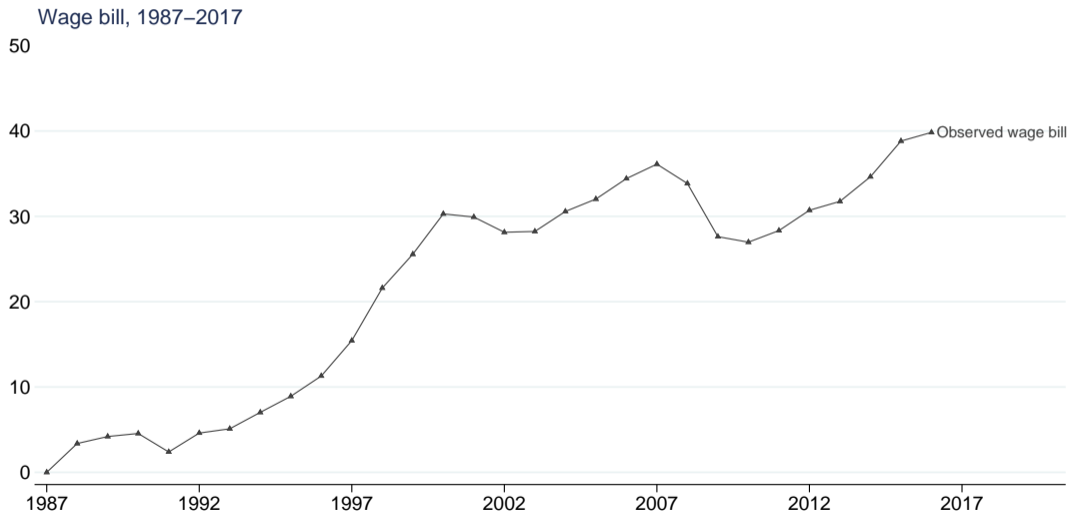
- ▶ Balanced technological change
 1. displacement of -0.5% per year
 2. reinstatement of 0.5% per year
 3. productivity effect of 2.5% per year
 4. Composition effects unimportant
- ▶ Labor demand tracks output
- ▶ Healthy growth of output per capita

4 Labor demand decomposition, 1987-2017.

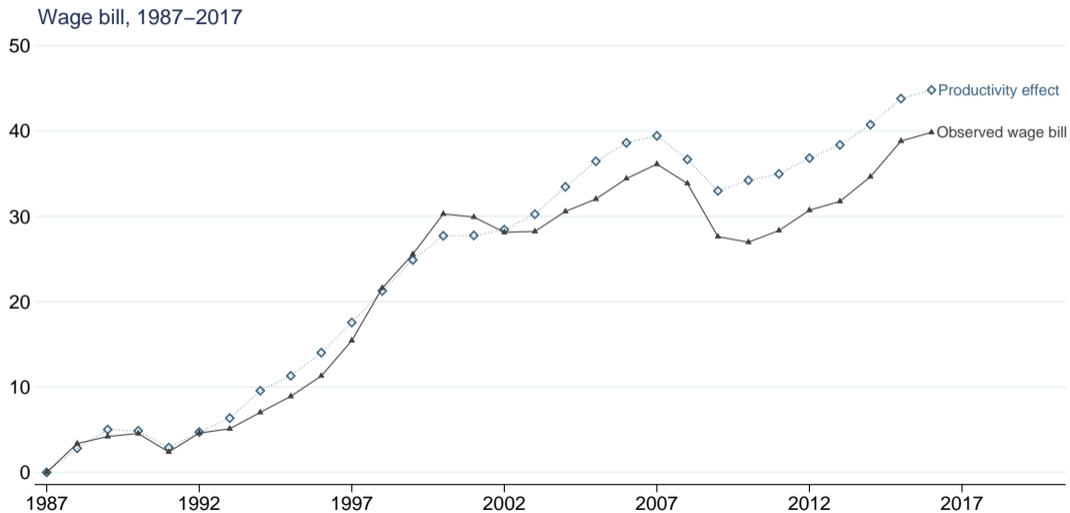
Decomposing Labor Demand: Data, 1987-2017



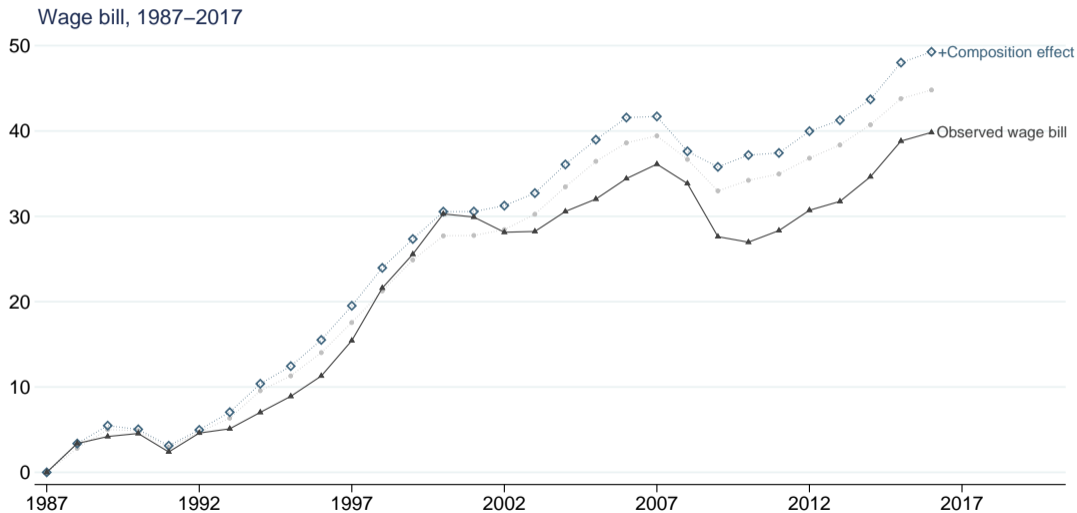
Decomposing Labor Demand: Decomposition, 1987-2017



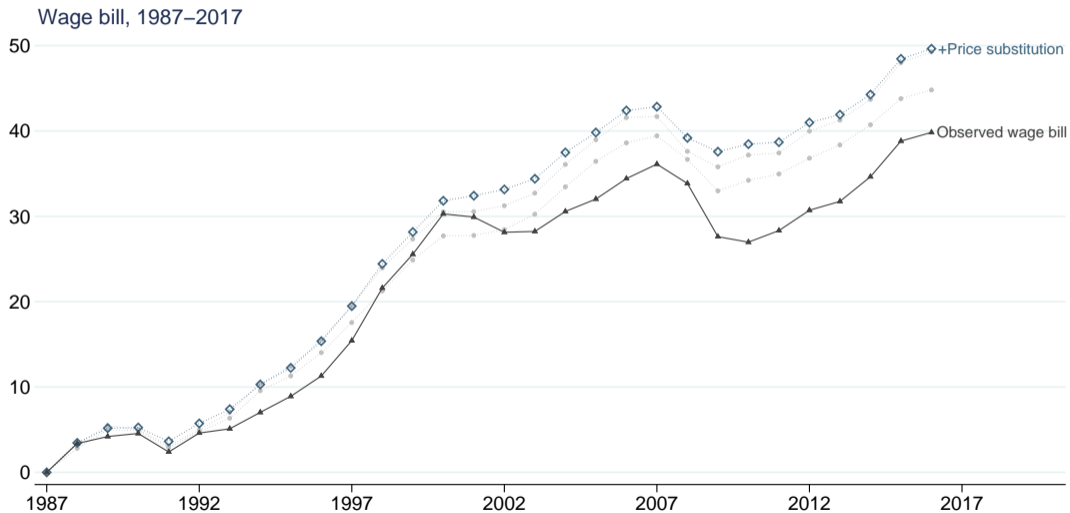
Decomposing Labor Demand: Decomposition, 1987-2017



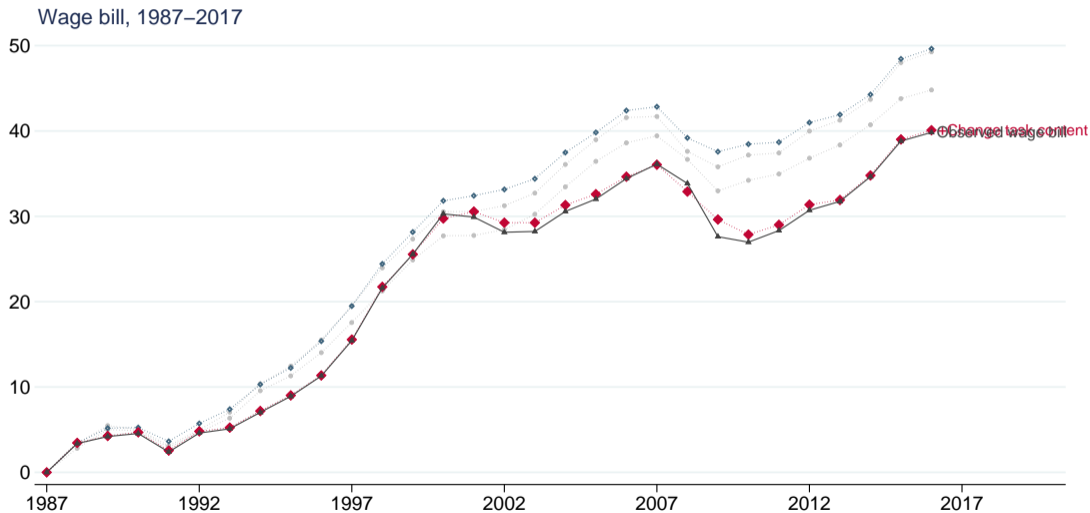
Decomposing Labor Demand: Decomposition, 1987-2017



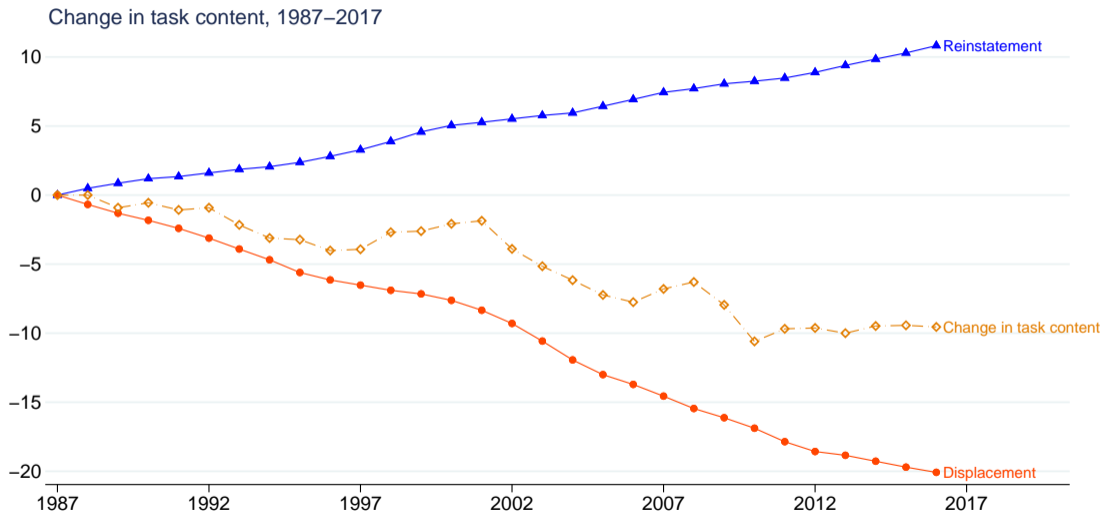
Decomposing Labor Demand: Decomposition, 1987-2017



Decomposing Labor Demand: Decomposition, 1987-2017



Displacement and Reinstatement, 1987-2017



Decomposing Labor Demand: Taking stock, 1987-2017

- ▶ Shift in technology
 1. displacement of -0.66% per year (vs 0.5% in earlier period)
 2. reinstatement of 0.4% per year (vs 0.5% in earlier period)
 3. productivity effect of 1.5% per year (vs 2.5% in earlier period)
 4. composition effects unimportant
- ▶ Anemic growth of output per capita
- ▶ Labor demand decouples from output

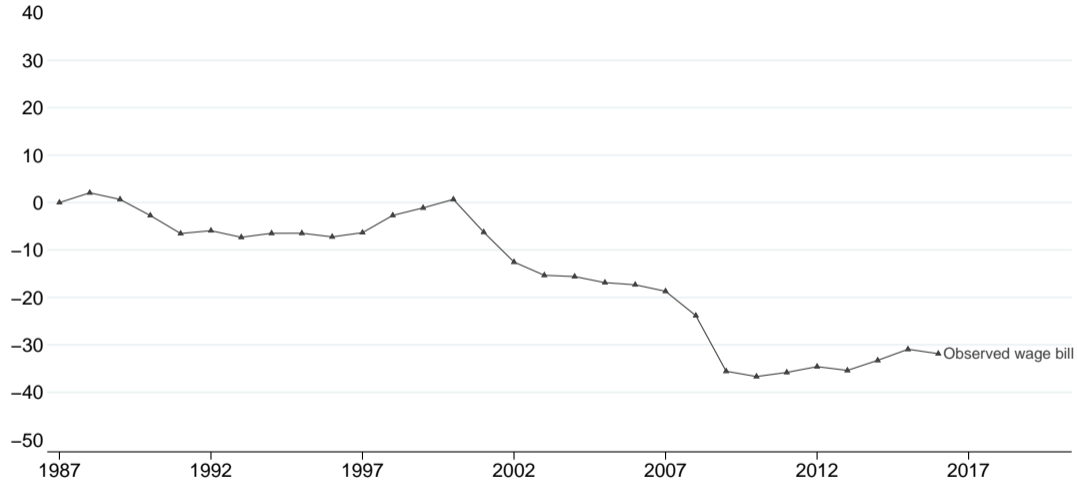
Decomposing Labor Demand: Manufacturing, 1987-2017

- ▶ Same framework to understand swift decline of manufacturing employment.

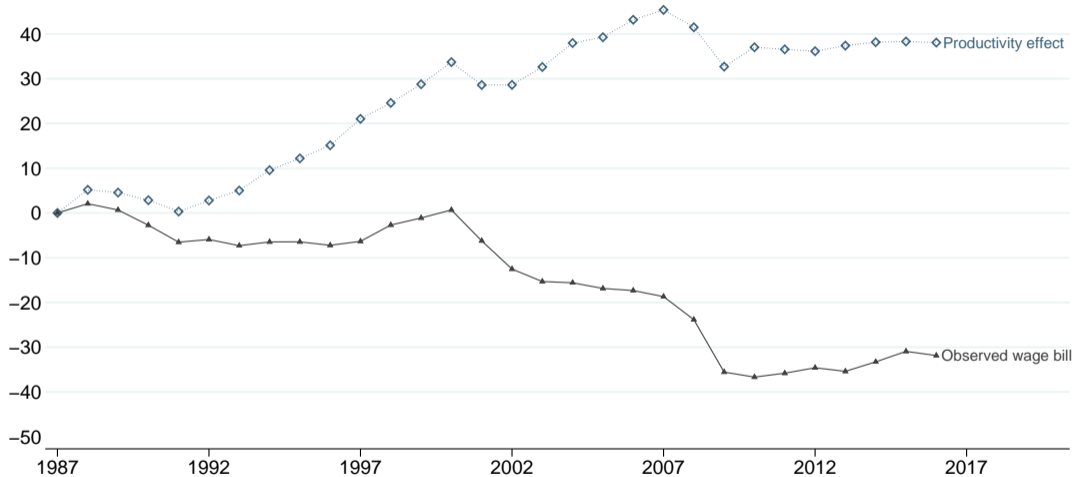
$$\begin{aligned}d \ln(WL)_{\text{manuf}} &= d \ln Y_{\text{manuf}} && \text{(Productivity effect)} \\ &+ d \ln P_{\text{manuf}} && \text{(Price effect)} \\ &+ \sum_{i \in \text{manuf}} \left(\frac{s_i^L}{s^L} - 1 \right) d \chi_i && \text{(Composition effect)} \\ &+ \sum_{i \in \text{manuf}} \ell_i \frac{1 - s_i^L}{1 - \Gamma_i} d \ln \Gamma_i && \text{(Task content)} \\ &+ \sum_{i \in \text{manuf}} \ell_i (1 - \sigma) (1 - s_i^L) \left(d \ln \frac{W_i}{A_i^L} - d \ln \frac{R_i}{A_i^K} \right) && \text{(Task-price subs) .}\end{aligned}$$

- ▶ **Price effect:** change in relative price of goods/ structural transformation.

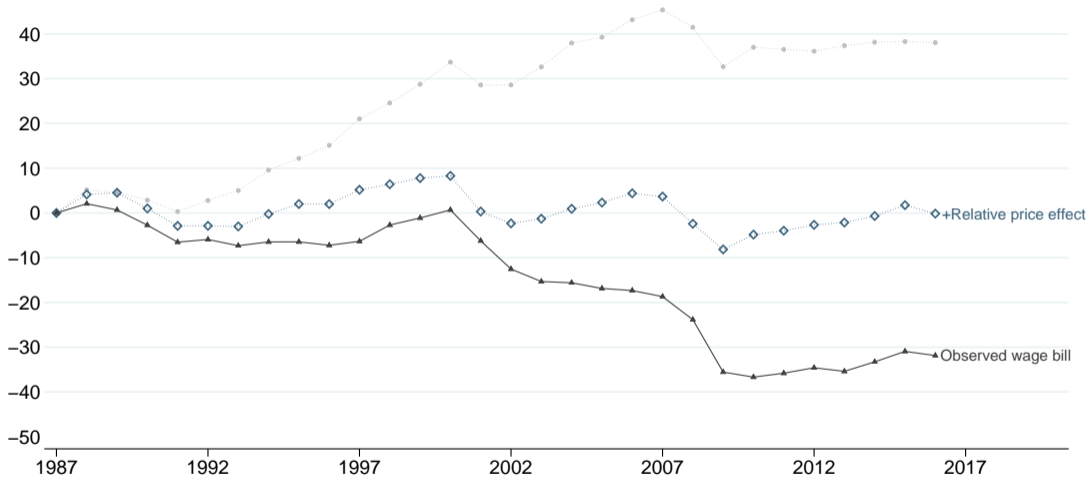
Manufacturing wage bill, 1987–2017



Manufacturing wage bill, 1987–2017



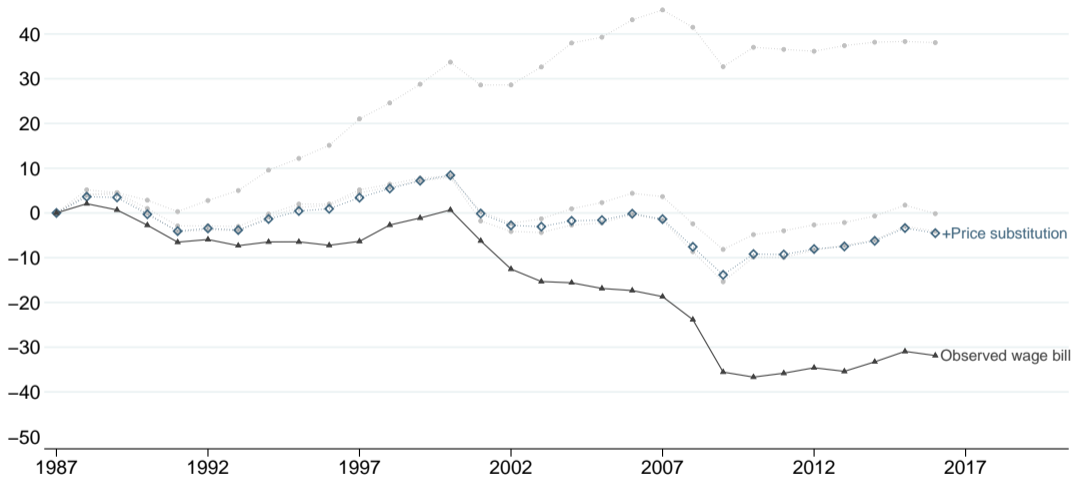
Manufacturing wage bill, 1987–2017



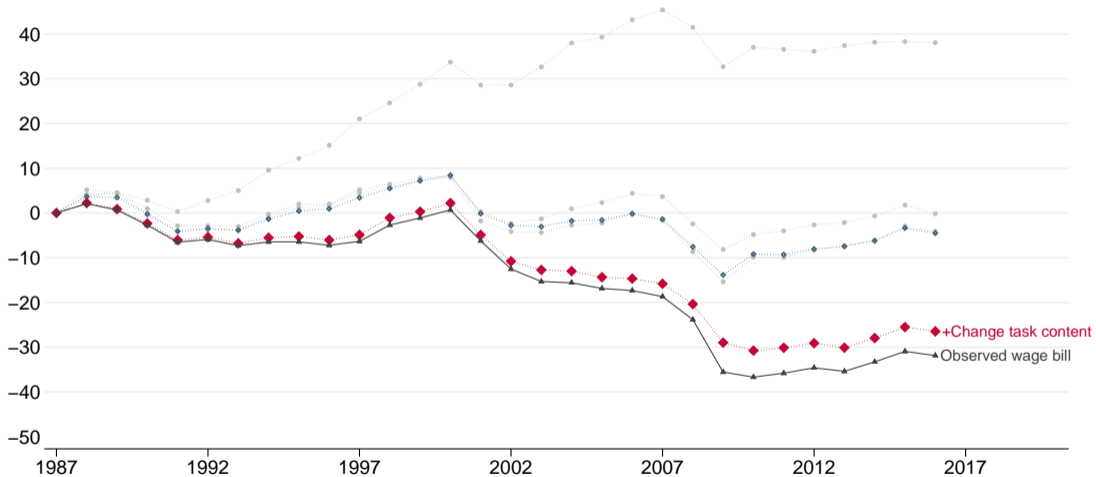
Manufacturing wage bill, 1987–2017



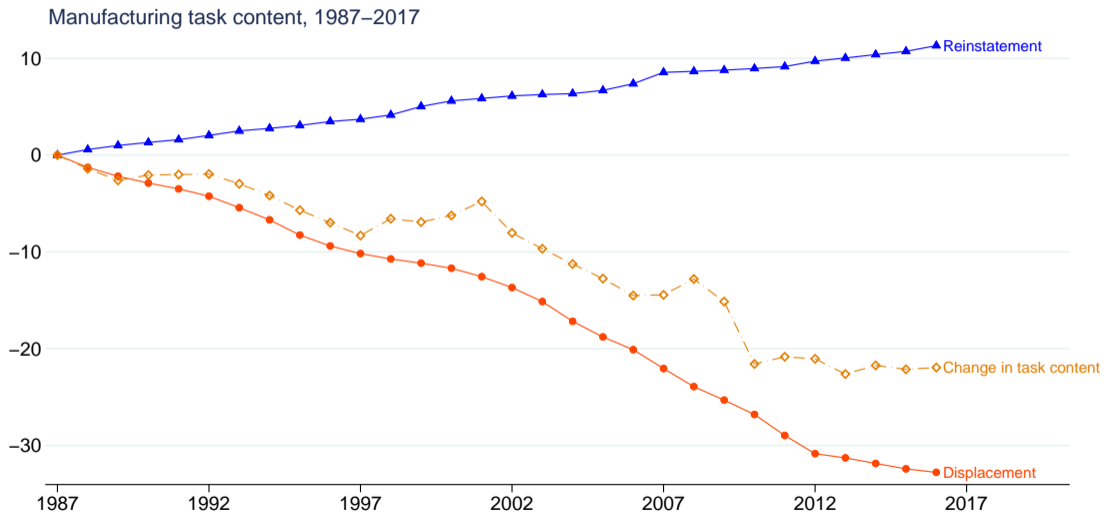
Manufacturing wage bill, 1987–2017



Manufacturing wage bill, 1987–2017



Displacement and Reinstatement, Manufacturing 1987-2017



Implications of shift in technology

- ▶ Labor demand decouples from output in 1987-2017
 - ▶ -10 log points of labor demand, -20 log points in manufacturing
- ▶ Is shift in technology partly responsible for anemic productivity growth?
 - ▶ what if new tasks had kept up with automation?
 - ▶ +10 log points in labor demand
 - ▶ +productivity gains from new tasks
 - ▶ +automation would have been more profitable
 - ▶ emphasis in so-so automation technologies
- ▶ Tech progress not slowing down, but changing in nature.
 - ▶ **tech has become less productivity and more labor-displacing.**

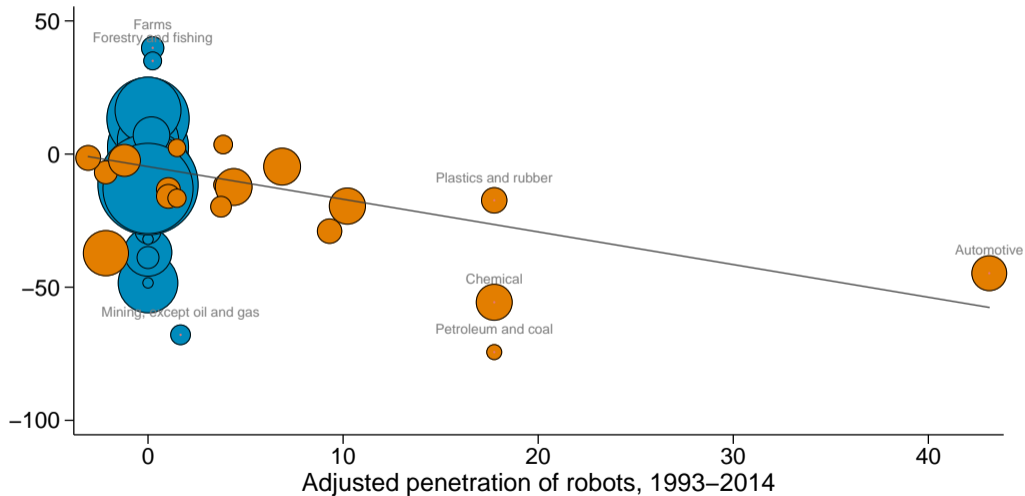
5 Correlates of change in task content across industries.

Change in task content, 1987–2017

Estimate: -1.23 (se= 0.34)

Controls for manufacturing: -0.82 (se= 0.30)

Controls for trade: -0.99 (se= 0.28)

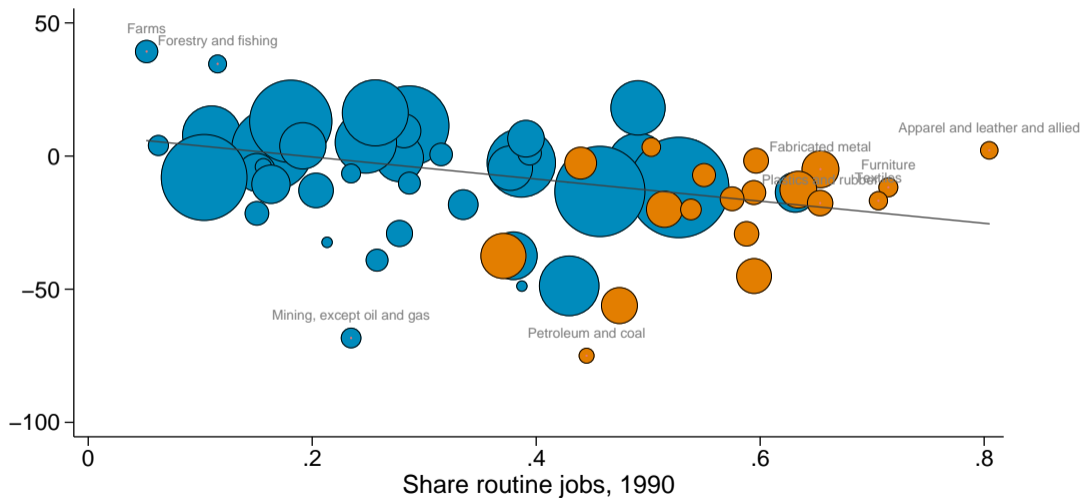


Change in task content, 1987–2017

Estimate: -41.54 (se= 12.02)

Controls for manufacturing: -25.04 (se= 15.34)

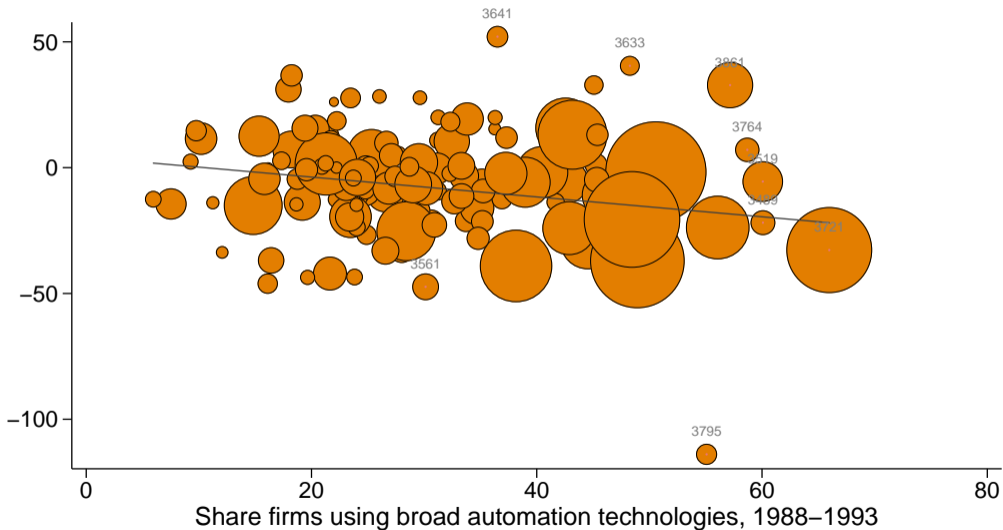
Controls for trade: -33.50 (se= 15.67)



Change in task content, 1987–2007

Estimate: -0.39 (se= 0.16)

Controls for trade: -0.44 (se= 0.16)



Explaining Changes in Task Content: Automation

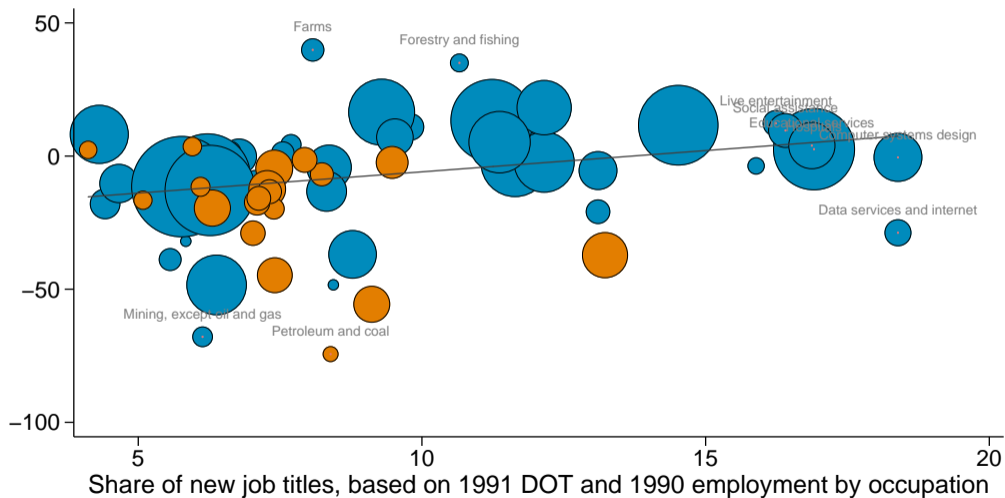
	RAW DATA	CONTROLLING FOR MANUFACTURING	CONTROLLING FOR CHINESE IMPORTS AND OFFSHORING
	(1)	(2)	(3)
<i>Proxies of automation technologies:</i>			
Adjusted penetration of robots, 1993-2014	-1.227 (0.341)	-0.817 (0.297)	-0.987 (0.282)
Observations	61	61	61
R-squared	0.17	0.23	0.29
Share routine jobs, 1990	-41.540 (12.018)	-25.041 (15.339)	-33.498 (15.666)
Observations	61	61	61
R-squared	0.15	0.21	0.29
<i>Detailed manufacturing industries (from SMT):</i>			
Share firms using broad automation technologies, 1988-1993	-0.395 (0.165)		-0.437 (0.165)
Observations	148		145
R-squared	0.08		0.12

Change in task content, 1987–2017

Estimate: 1.60 (se= 0.52)

Controls for manufacturing: 1.31 (se= 0.52)

Controls for trade: 1.53 (se= 0.53)

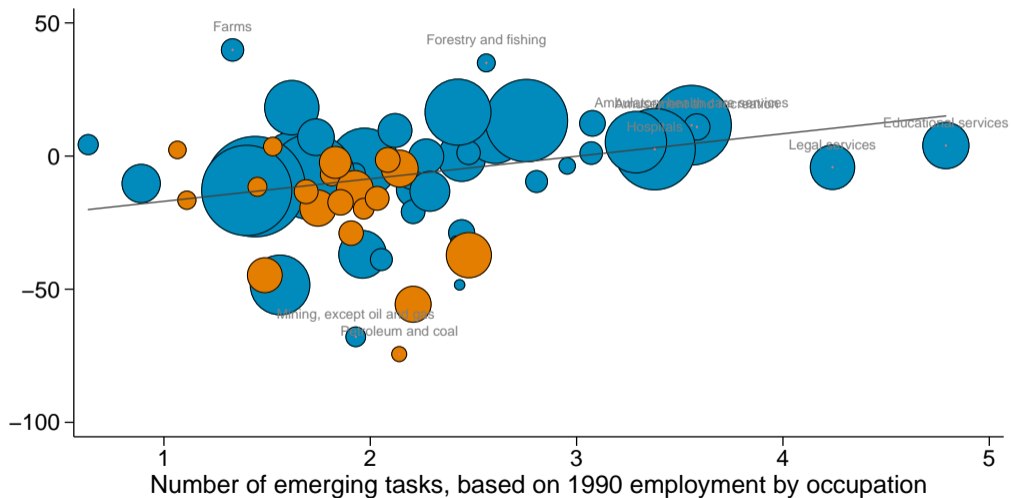


Change in task content, 1987–2017

Estimate: 8.46 (se= 2.21)

Controls for manufacturing: 7.07 (se= 2.29)

Controls for trade: 7.66 (se= 2.34)

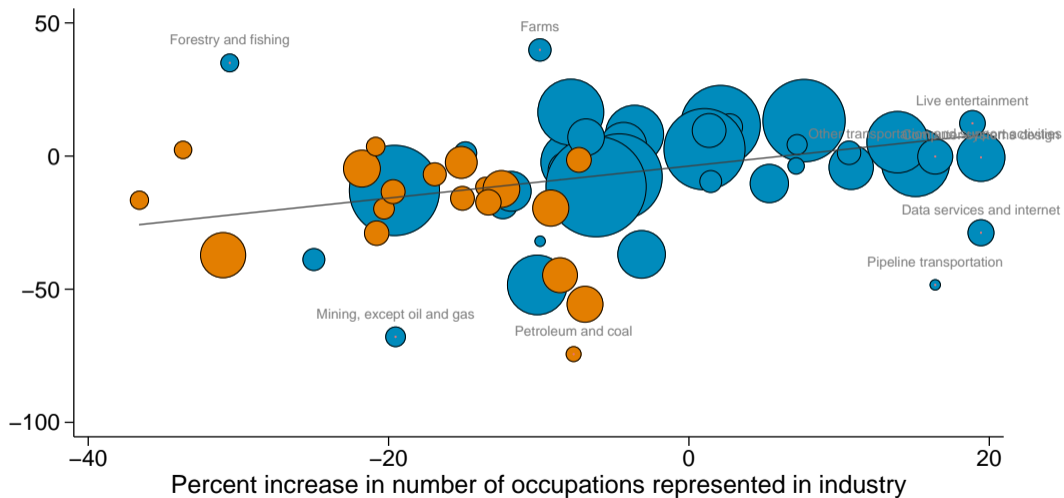


Change in task content, 1987–2017

Estimate: 0.60 (se= 0.15)

Controls for manufacturing: 0.38 (se= 0.19)

Controls for trade: 0.38 (se= 0.20)



Explaining Changes in Task Content: New tasks

	RAW DATA	CONTROLLING FOR MANUFACTURING	CONTROLLING FOR CHINESE IMPORTS AND OFFSHORING
	(1)	(2)	(3)
<i>Proxies of new tasks:</i>			
Share of new job titles, based on 1991 DOT and 1990 employment by occupation	1.597 (0.517)	1.308 (0.519)	1.531 (0.526)
Observations	61	61	61
R-squared	0.12	0.25	0.32
Number of emerging tasks, based on 1990 employment by occupation	8.460 (2.215)	7.071 (2.289)	7.663 (2.335)
Observations	61	61	61
R-squared	0.15	0.27	0.33
Percent increase in number of occupations represented in industry	0.602 (0.153)	0.375 (0.195)	0.382 (0.199)
Observations	61	61	61
R-squared	0.15	0.21	0.26

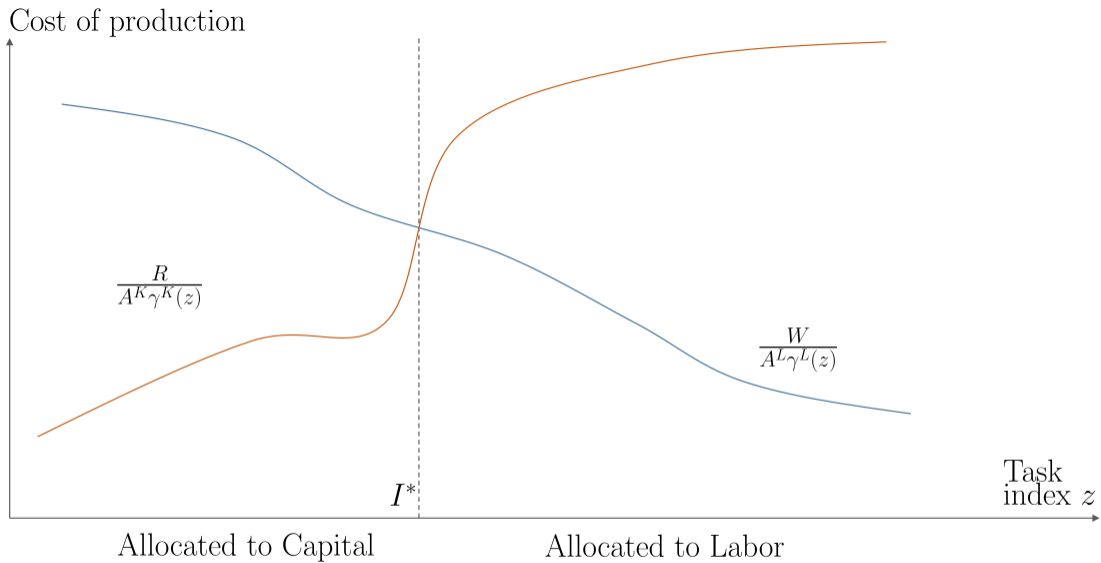
6 Concluding remarks.

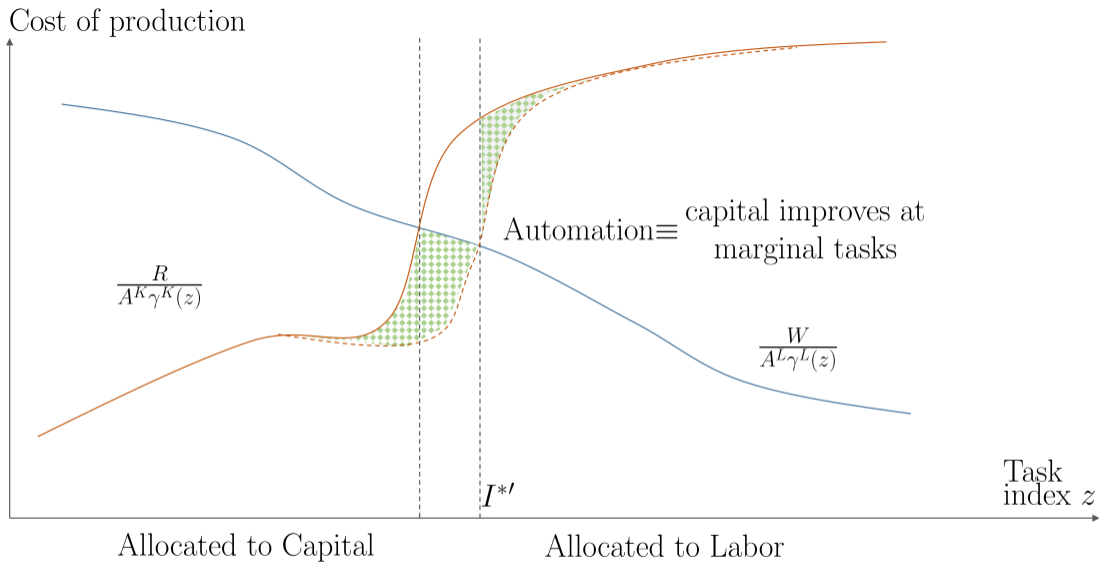
Concluding Remarks: Future Steps

- ▶ Think hard and carefully about what technologies do before running regressions.
- ▶ Develop techniques to infer changes in task content from microdata
- ▶ Direct measures of task allocation. Does it matter for wages?
- ▶ Separate role of markups/monopsony
- ▶ Implications of changes in task content for inequality
- ▶ Much more work on “new tasks.” Do they emerge seamlessly as a byproduct of automation/growth or are they a deliberate effort to reinstate labor.
- ▶ Major question: why is reinstatement weak? Is it that the innovation possibilities frontier has changed? Are incentives for directing technology skewed?

... Extra material.

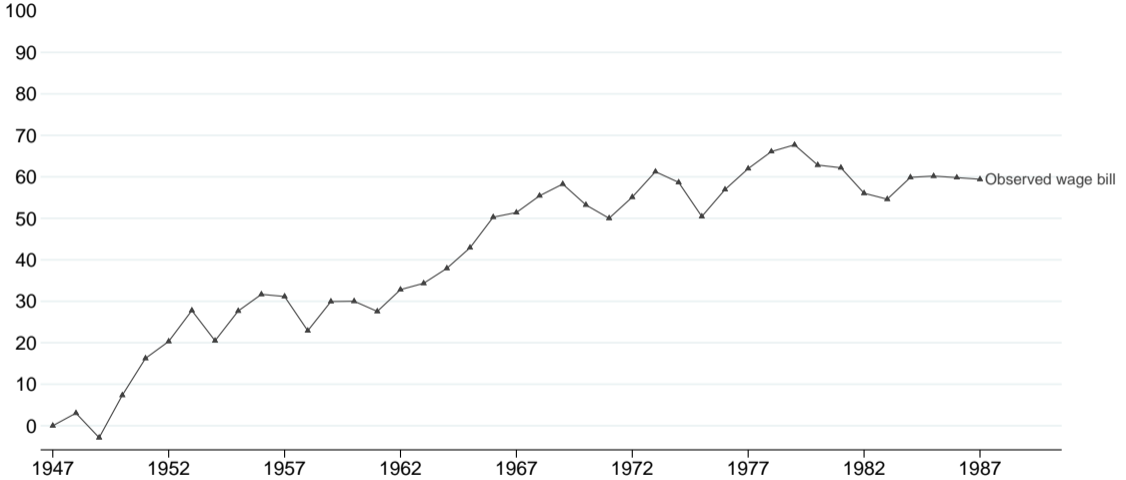
A1 Feasibility restriction does not bind



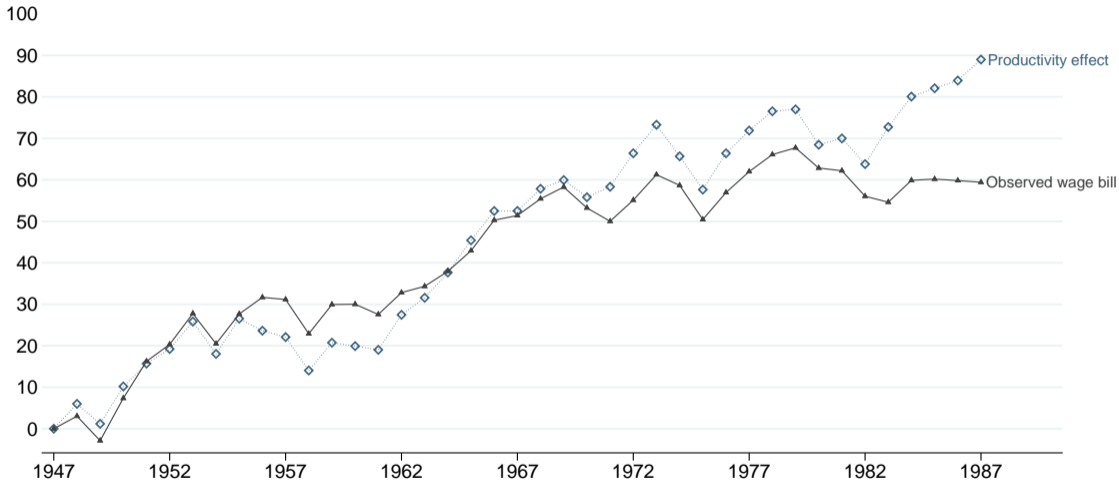


A2 Manufacturing in 1947-1987

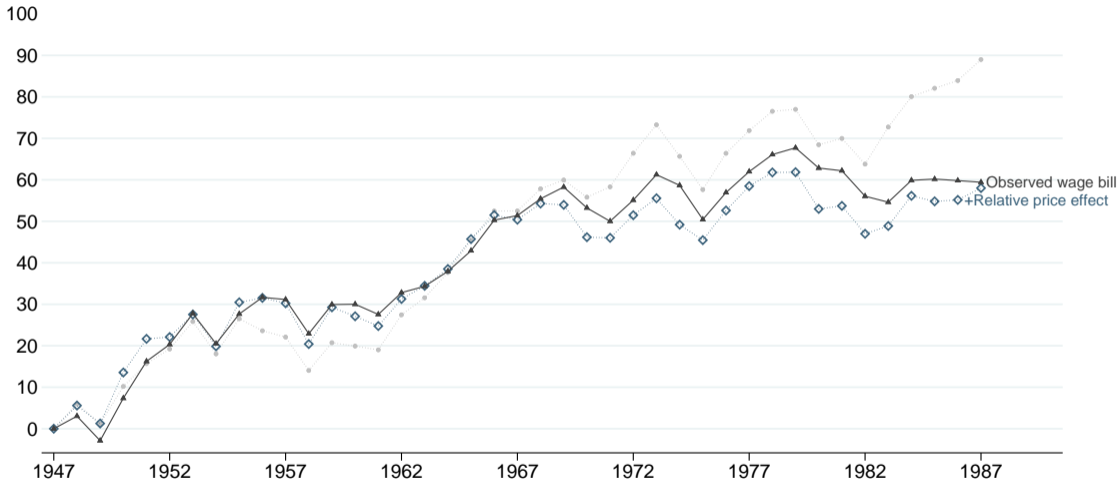
Manufacturing wage bill, 1947–1987



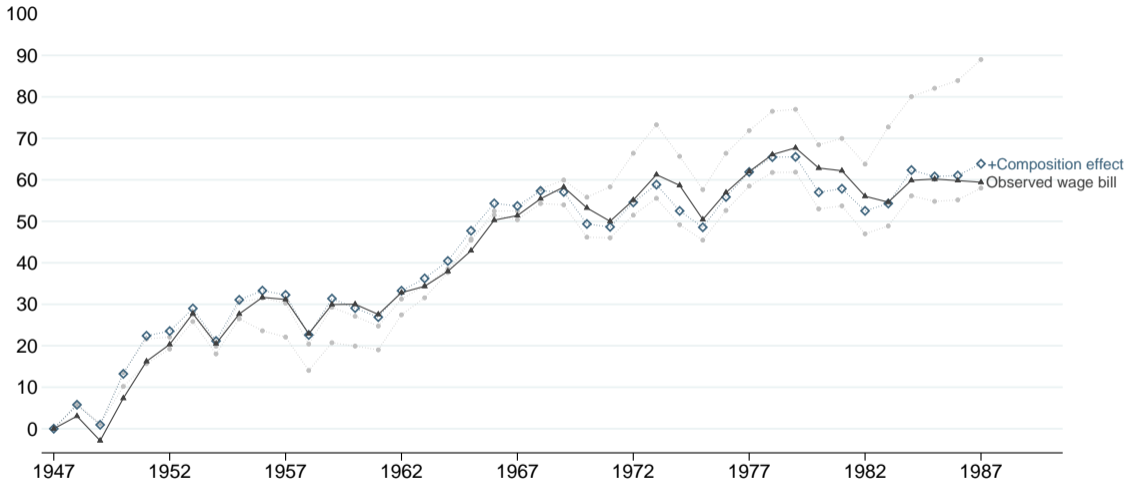
Manufacturing wage bill, 1947–1987



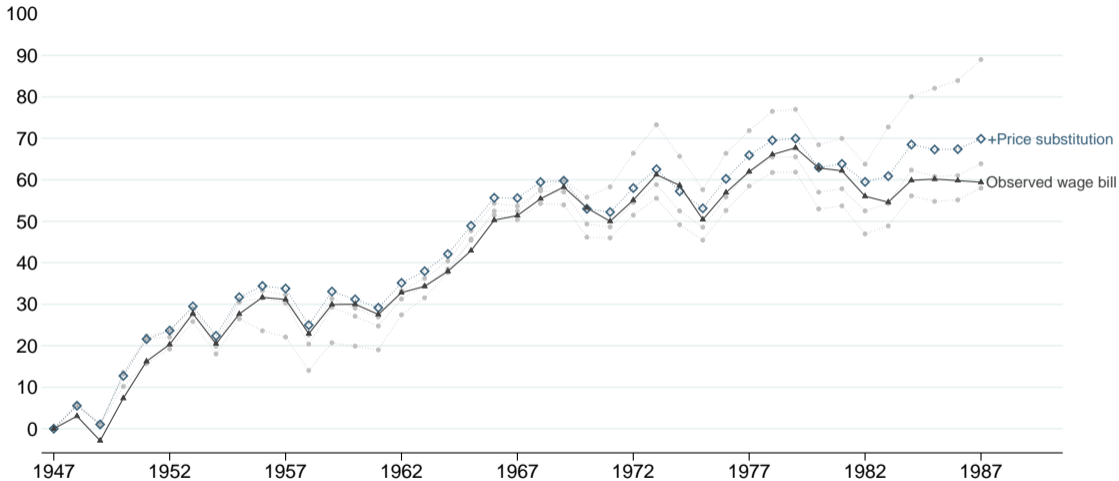
Manufacturing wage bill, 1947–1987



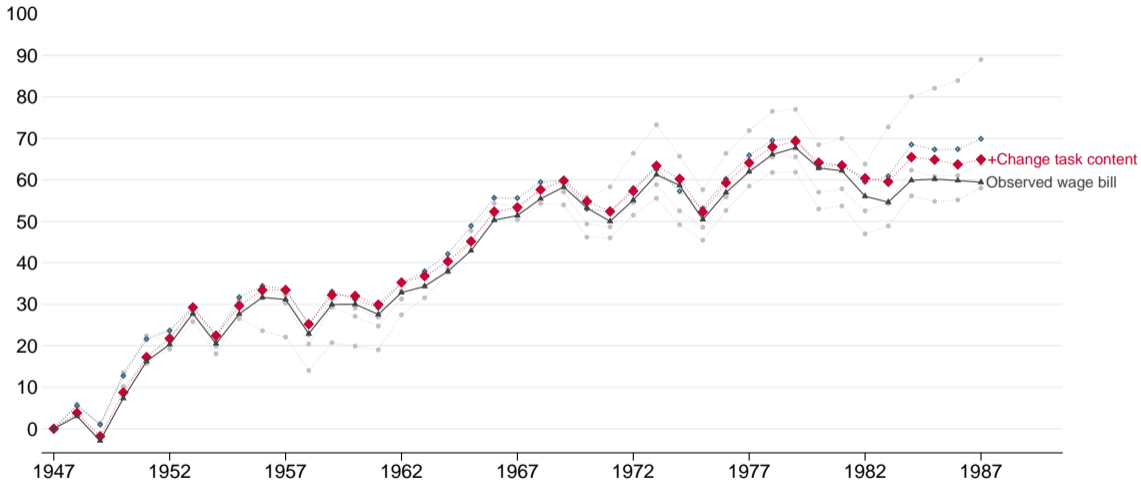
Manufacturing wage bill, 1947–1987



Manufacturing wage bill, 1947–1987

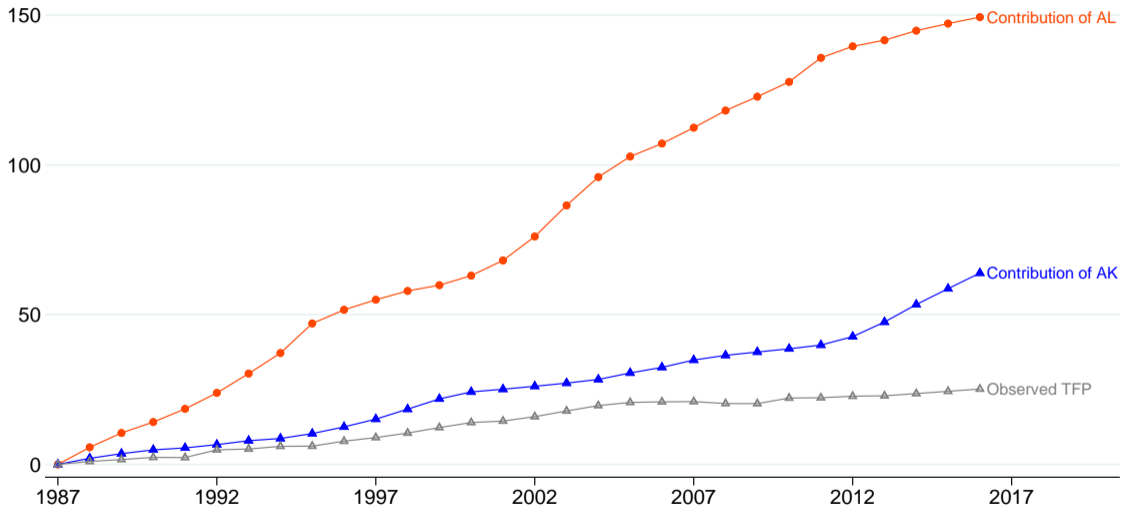


Manufacturing wage bill, 1947–1987



A3 Factor-augmenting technologies cannot explain displacement and reinstatement

Implied TFP growth, 1987–2017



Implied TFP growth, 1947–1987

