Automation and the Labor Share

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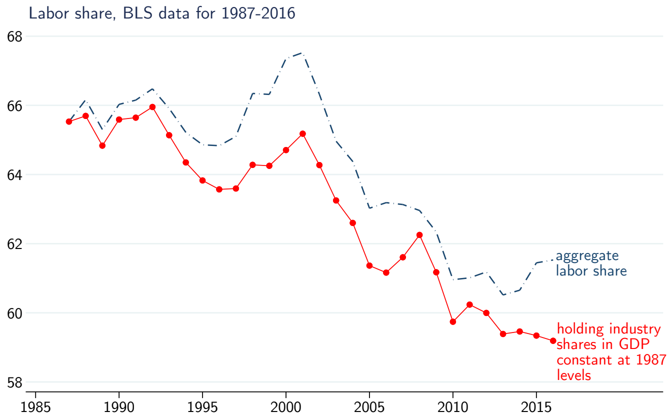
Introduction



- What accounts for this notable decline in the labor share?
- Capital deepening? Markups? Monopsony?
- Often overlooked: **automation**

This Paper

- **Theory:**
  - automation (e.g., adoption of industrial robots) has first-order effect on labor share;
  - it cannot be understood through the usual factor-augmenting technological changes and capital-labor substitution channels;
  - it should instead be studied in the context of task-based models.
- **Empirics:**
  - in the US the labor share decline is mostly in the manufacturing sector;
  - in manufacturing, decline concentrates in industries undergoing rapid automation;
  - in firm-level data from France, labor share increases in firms not adopting robots and declines in firms adopting robots—leading to an overall decline in the labor share in manufacturing.

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

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

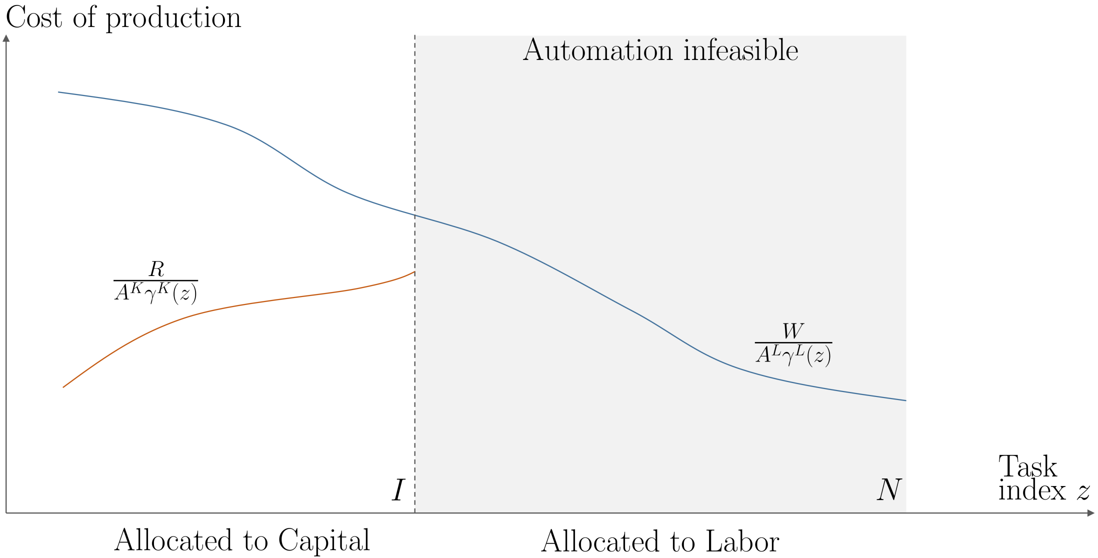
Output — Task services — Elast of substitution

- Tasks can be produced using capital or labor:

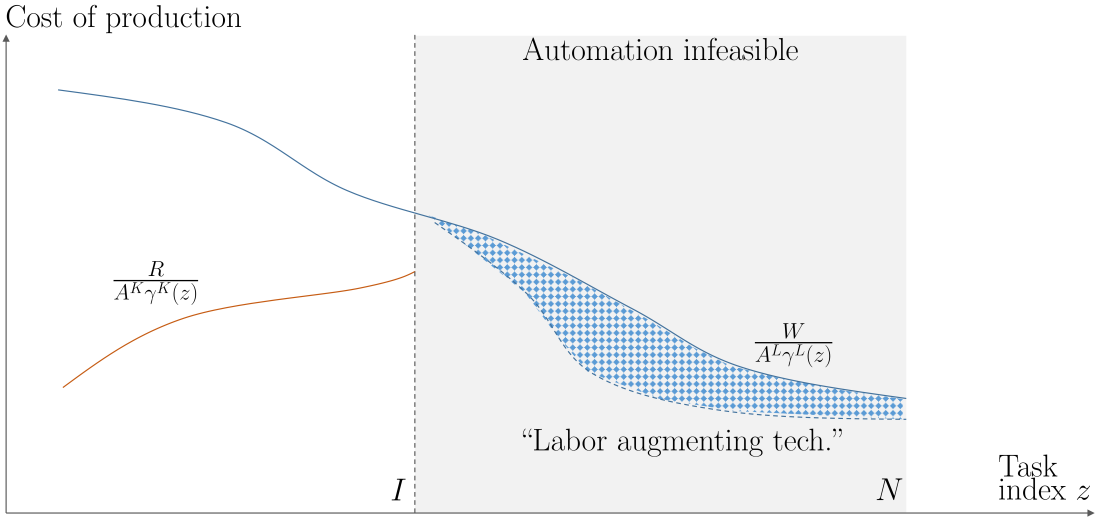
$$\mathcal{Y}(z) = \begin{cases} A^L \gamma^L(z) \ell(z) + A^K \gamma^K(z) k(z) & \text{if } z \in [N-1, I] \\ A^L \gamma^L(z) \ell(z) & \text{if } z \in (I, N]. \end{cases}$$

Feasible to automate — New tasks

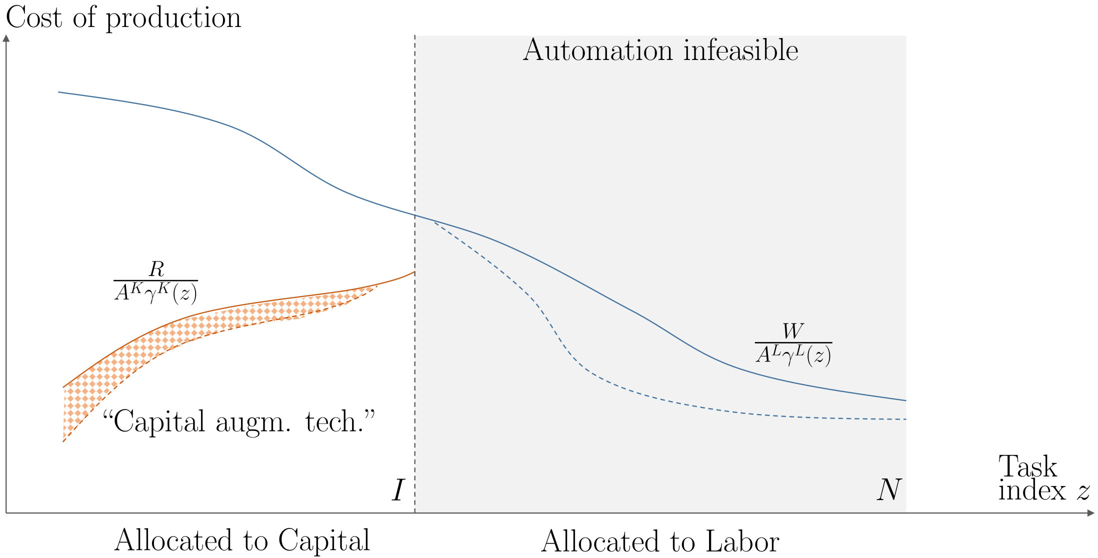
- *Comparative advantage:* $\gamma^L(z)/\gamma^K(z)$ and $\gamma^L(z)$ increasing in z.



Cost of production
Automation infeasible
$\frac{R}{A^K \gamma^K(z)}$
$\frac{W}{A^L \gamma^L(z)}$
I
N
Task index z
Allocated to Capital
Allocated to Labor



Cost of production
Automation infeasible
$\frac{R}{A^K\gamma^K(z)}$
$\frac{W}{A^L\gamma^L(z)}$
"Labor augmenting tech."
I
N
Task index z



Cost of production
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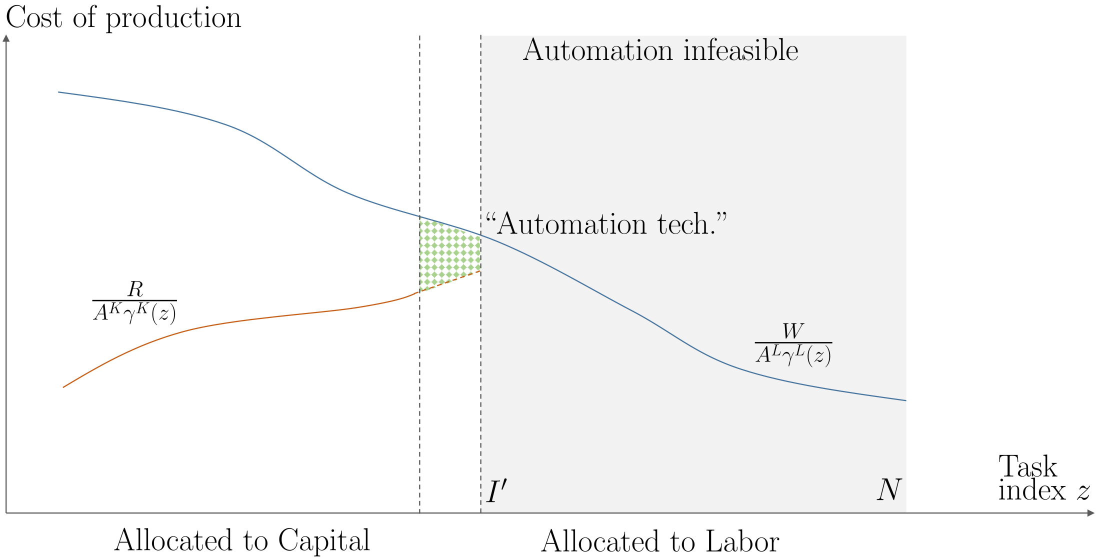
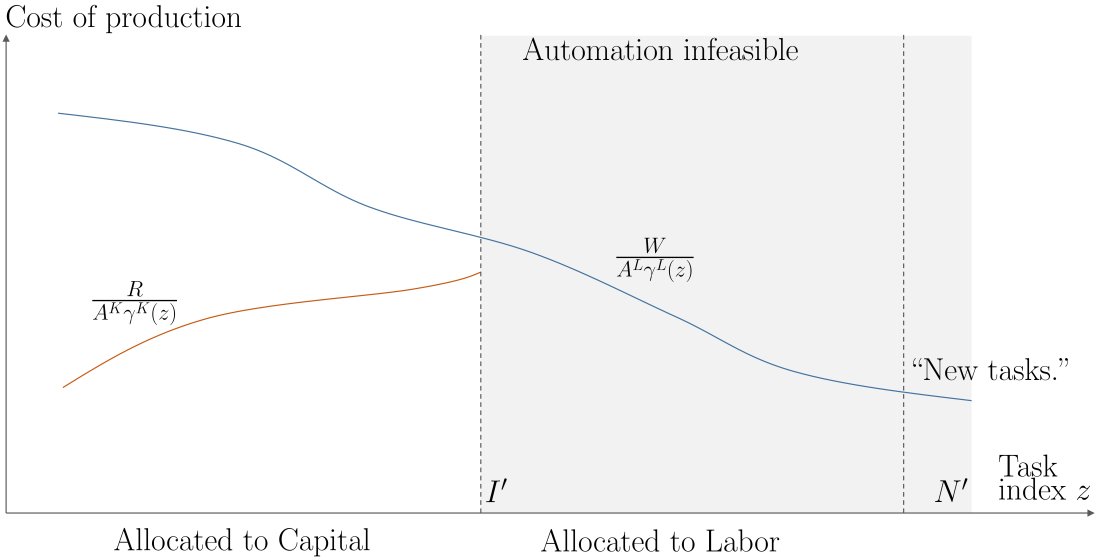


Cost of production
Automation infeasible
"Automation tech."
$\frac{R}{A^K\gamma^K(z)}$
$\frac{W}{A^L\gamma^L(z)}$
I'
N
Task index z
Allocated to Capital
Allocated to Labor


Cost of production
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$\frac{W}{A^L \gamma^L(z)}$
$\frac{R}{A^K \gamma^K(z)}$
“New tasks.”
I'
N'
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Thinking in Terms of Tasks: Aggregate Representation

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

- A^K, A^L summarize all forms of factor-augmenting technologies.
- I, N summarize role of automation and new tasks.
- $\Gamma(N,I)$=task content of production (equal to $N-I$ when $\gamma^K(z)=\gamma^L(z)=1$ or $\sigma=1$).
- The labor share is given by

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

- Factor-augmenting technologies and automation work through different channels.
- Automation always reduces the labor share regardless of the value of σ.

Thinking in Terms of Tasks: Labor Demand

- The labor share also determines labor demand:

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

Output

Labor share

Wage bill as
measure of labor demand

- For now, ignoring markups and other non-competitive elements.

Automation and Labor Demand

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

$$+ \frac{1}{\sigma}\frac{1-s^L}{1-\Gamma(N,I)}\frac{\partial \ln \Gamma(N,I)}{\partial I} \quad \text{(Displacement effect<0)}$$

- In the absence of the displacement effect, the wage bill changes proportionately to output, and the labor share is constant.
- Because the displacement effect is negative, wage bill increases less than output.
- Net effect on wage bill 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.

Factor-Augmenting Technologies and Labor Demand

$$\frac{\partial \ln WL}{\partial \ln A^L} = s^L \qquad \text{(Productivity effect)}$$

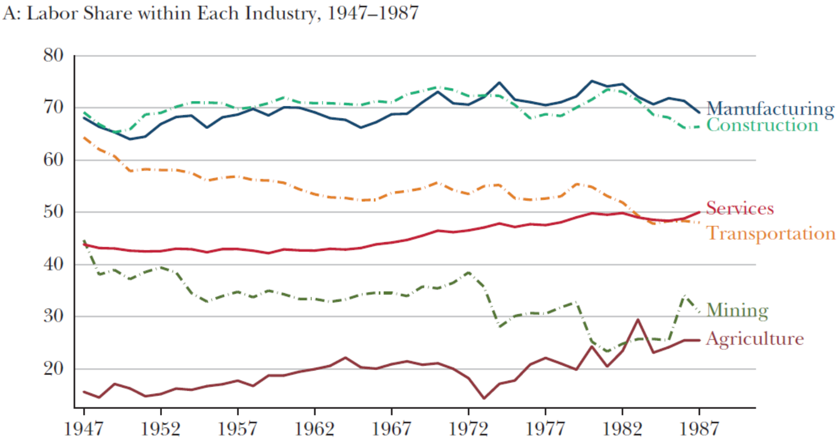
$$+ \frac{\sigma - 1}{\sigma}(1 - s^L) \qquad \text{(Task-price substitution)},$$

$$\frac{\partial \ln WL}{\partial \ln A^K} = (1 - s^L) \qquad \text{(Productivity effect)}$$

$$+ \frac{1 - \sigma}{\sigma}(1 - s^L) \qquad \text{(Task-price substitution)}.$$

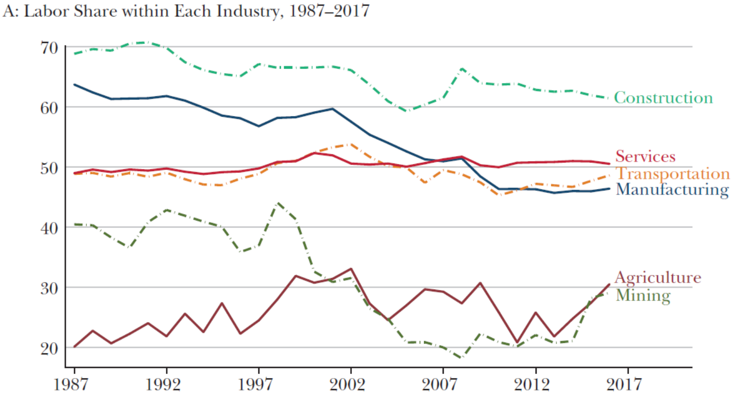
- No displacement or reinstatement effect; task content unchanged.
- Task-price subs effect small ($\sigma \approx 1$) relative to productivity effect:
  - affect labor demand through productivity
  - changes in labor share concur with huge productivity increases

Where Does the Labor Share Decline Comes from? 1947-1987



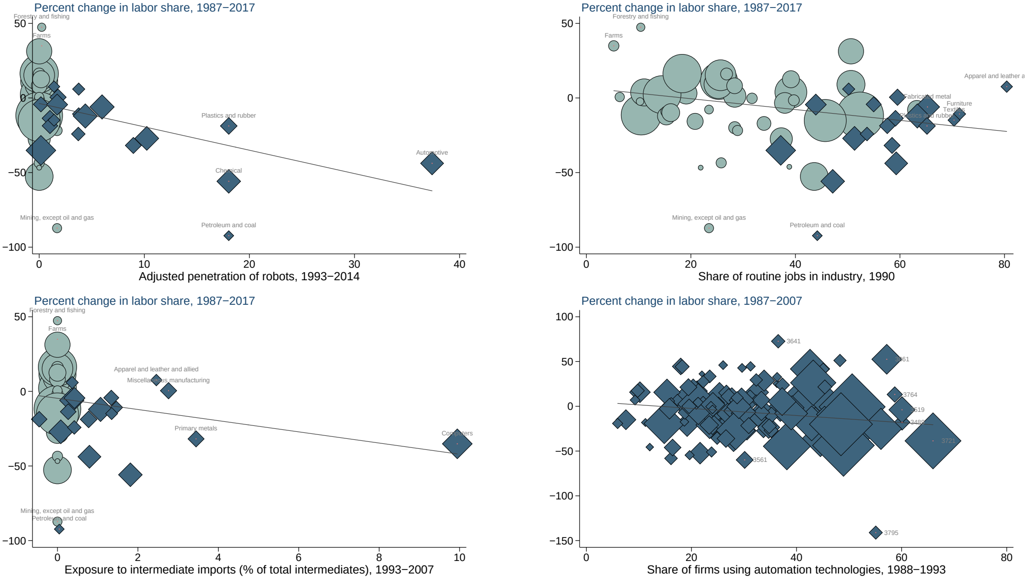
- Important to look at labor share in value added (not sales, since the share of intermediates in sales is increasing over time).

Where Does the Labor Share Decline Comes from? 1987-2017



- Some declines in labor share in wholesale and retail during this time period.
- But the decline in the labor share is mostly a manufacturing phenomenon.

Automation and the Labor Share: Industry Evidence



Robustness

Table: Relationship between labor share and proxies for automation.

	Raw data	Controlling for manufacturing	Controlling for Chinese import and offshoring
	(1)	(2)	(3)
Proxies for automation technologies:			
Adjusted penetration of robots, 1993-2014	-1.567	-1.080	-1.149
	(0.429)	(0.385)	(0.394)
Observations	61	61	61
R-squared	0.19	0.23	0.27
Share of routine jobs in industry, 1990	-0.363	-0.157	-0.230
	(0.143)	(0.192)	(0.200)
Observations	61	61	61
R-squared	0.10	0.18	0.25
Detailed manufacturing industries (SMT):			
Share of firms using automation technologies, 1988-1993	-0.396		-0.409
	(0.224)		(0.218)
Observations	148		148
R-squared	0.05		0.10

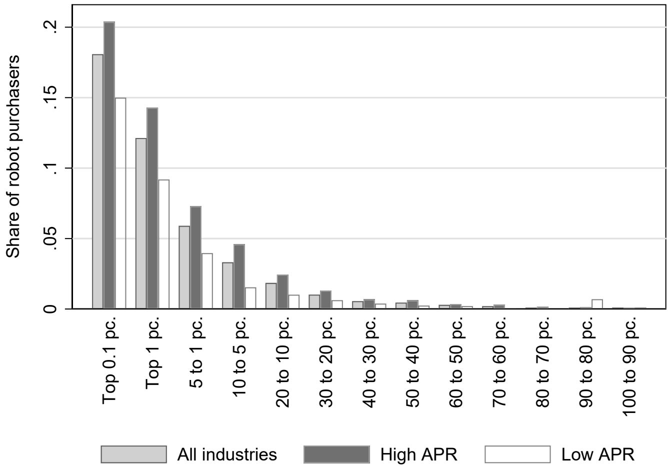
Quantitative Magnitudes and Interpretation

- Let's focus on industrial automation, of which industrial robots are a key component.
- Penetration of robots explain 20% of the variation in changes in the labor share across industries (32% within manufacturing).
- Each additional robot per thousand workers associated with a 1% decline in the manufacturing labor share.
- Increase in robot use of close to 10 robots per thousand workers in manufacturing could account for up to 10% out of the 30% decline in the labor share of the sector.
- A sizable portion of the decline in the labor share in US manufacturing seems to be accounted for by industrial automation.

French Data on Robots

- Sample of 55,390 firms that were active from 2010 to 2015 in the French manufacturing sector.
- Subset of 598 firms that purchased industrial robots in this period.
- Identified from several sources:
  - survey by the French Ministry of Industry
  - clients' lists provided by French robot suppliers and integrators
  - customs data on imports of industrial robots by firm
  - fiscal files with information on robot depreciation allowances
- Although only 1% of the firms purchased robots in 2010-2015, these firms account for 20% of total manufacturing employment.

Robot Adoption in French Manufacturing



- Robot adopters are larger and concentrate in industries where there are major advances in robotics technology and rapid spread of robots in other countries.

Estimating Equation

- Estimating equation:

$$\Delta \ln y_f = \beta \cdot \text{Robot}_f + \eta \cdot \text{Adoption by competitors}_f \qquad (1)$$
$$\gamma \cdot X_f + \alpha_{i(f)} + \delta_{c(f)} + \varepsilon_f .$$

where

$$\text{Adoption by competitors}_f = \sum_i m_{fi} \cdot \sum_{f' \neq f} s_{if'} \cdot \text{Robot}_{f'} .$$

- First sum over all 4-digit industries; m_{fi} is the share of firm f sales in industry i.
- The second sum is over all firms other than f and $s_{if'}$ is the share of industry i sales accounted for by firm f'.
- Measure of adoption by competitors gives the overlap in terms of sales across 4-digit industries between a firm and all robot adopters in the economy.
- Unweighted and baseline employment-weighted OLS estimates (no firm-level exogenous source of variation in robot adoption).

Results

Table: Estimates of robot adoption on adopters and competitors

	Unweighted estimates			*Employment-weighted estimates*		
	(1)	(2)	(3)	(4)	(5)	(6)
	Δ log employment (in hours)	Δ log value added	Δ labor share	Δ log employment (in hours)	Δ log value added	Δ labor share
Robot adoption by competitors	-0.105	-0.100	0.002	-0.250	-0.209	-0.008
	(0.047)	(0.051)	(0.015)	(0.107)	(0.159)	(0.040)
Robot adopter	0.106	0.201	-0.043	0.035	0.078	-0.027
	(0.020)	(0.030)	(0.009)	(0.022)	(0.029)	(0.012)
R^2	0.093	0.083	0.161	0.190	0.217	0.274

Quantitative Magnitudes and Interpretation

- Robot adoption associated with a 4.3 pp reduction in the labor share of a firm.
- Robot adopters make up 20% of value added, and thus their decline in labor share accounts for a 0.86 pp decline in the manufacturing labor share.
- This is approximately the decline in French manufacturing over this time period.
- Lower value added and employment in a firm when competitors adopt robots.
- Consistent with theory, competitors' adoption has no impact on own labor share.

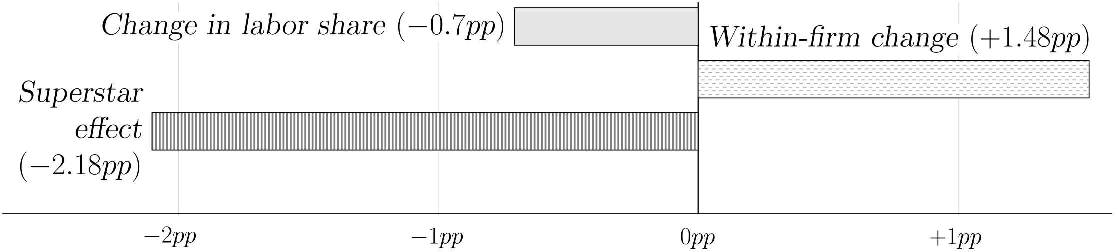
Superstar Effects and the Labor Share

- The impact of robot adoption on overall labor share is greater than impact on own labor share—because of reallocation documented above.
- The issue is very similar to that studied by Autor et al. (2019).
- They propose the following decomposition (only for surviving firms here)

Change in labor share	=	Within firm change: Change in unweighted mean	+	Superstar effect: Change in covariance between labor share and value added

Superstar Effect in French Manufacturing

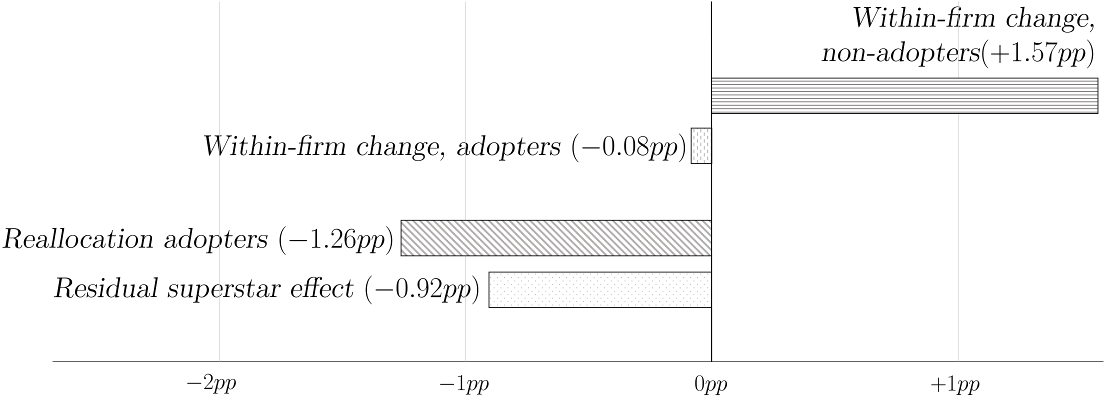
- There is a similar superstar effect in French manufacturing:



- This is similar to the results from the US in Autor et al. (2019).

Robots and Superstar Effects

- But we can now further understand the role of automation in this process.



- Very different patterns for robot adopters and non-adopters.
- Also, changes for these two groups account for two thirds of the superstar effects.

Robots and Superstar Effects (continued)

- Further decompose the contribution of robot adoption to the superstar effect in three terms:

$$\underbrace{(s_{\mathcal{R}_i} - f_i) \times \Delta(\bar{\lambda}^{\ell}_{\mathcal{R}_i} - \bar{\lambda}^{\ell}_{\mathcal{N}_i})}_{\text{size correction}} + \underbrace{(\bar{\lambda}^{\ell}_{\mathcal{R}_i} - \bar{\lambda}^{\ell}_{\mathcal{N}_i}) \times \Delta s_{\mathcal{R}_i}}_{\text{pure reallocation}} + \underbrace{\Delta(\bar{\lambda}^{\ell}_{\mathcal{R}_i} - \bar{\lambda}^{\ell}_{\mathcal{N}_i}) \times \Delta s_{\mathcal{R}_i}}_{\text{directed reallocation}},$$

- The superstar effect for adopters is mostly about the fact that labor share declines in these firms that account for a large fraction of value added.
- No “pure reallocation effect”—because no baseline differences in labor share between adopters and non-adopters (74% versus 76% in the two groups).
- This suggests a large role for adoption (and much less for any markup differences or baseline capital efficiency differences).

Conclusion

- Theoretically, automation should have a first-order impact on the labor share.
- There has been a lot of automation in manufacturing (perhaps also in some other sectors recently but less well understood).
- Much of the decline in the labor share in the US concentrates in manufacturing.
- Within manufacturing, industries undergoing rapid automation is where we see the decline in the labor share.
- In firm-level data from French manufacturing, we see no decrease in the labor share (in fact an increase) among firms not adopting robots, but declines overall and among firms adopting robots.
- A lot of the changes in the labor share may be about automation.