What Are the Labor and Product Market Effects of Automation? New Evidence from France

Philippe Aghion, *College de France*
Celine Antonin, *OFCE*
Simon Bunel, *Banque de France and PSE*
Xavier Jaravel, *London School of Economics*

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Motivation

- Why did major technological revolutions (steam engine, electricity) not generate mass unemployment anticipated by some?

  - Luddites in 1811-1812
  - Keynes (1930): technological unemployment

- Policy implications: **robot tax** (Bill Gates, Andrew Yang, Benoît Hamon)

- Tradeoff: **displacement vs. productivity**
  (e.g., Zeira 1998, Acemoglu-Restrepo 2019)

  - Automation is labor-**displacing** at task level
  - But could induce **productivity** gains, lower prices, higher demand, and need for implementing new tasks

- Several challenges when assessing this tradeoff empirically

  - Measurement of *automation*
  - Net effect likely depends on level of aggregation

This paper

- French manufacturing industry between 1995 and 2017 to analyze the effects of automation on:
  - ▶ Employment
  - ▶ Sales, wages, within-firm inequality, prices, and profits

- Measure automation from:
  - ▶ Balance sheet value of industrial machines
  - ▶ Records of usage of electro-motive power
  - ▶ Imports of specific CN8 industrial machines

This paper

- Event studies at firm level
  - Exploiting timing of adoption of industrial machines across firms (in same industry)

- Firm-level IV analysis using shift-share design
  - Research design combines (a) changes in the productivity of foreign suppliers of machines ("shifts"), with (b) pre-existing import shares ("exposure shares")

- Repeat analysis at the industry level to account for business-stealing and other equilibrium effects

This paper: Main Findings - Firm level

- Consistent with **productivity effect**:
  - ▶ Automation ↑, marginal cost and prices ↓, demand ↑, employment ↑

- Event studies indicate that increased automation leads to:
  - ▶ At firm-level, a **1% increase in automation** at year t leads to a **0.2% increase in employment at t**, and a **0.4% increase after 10 years**
  - ▶ Automation **increases job creation and job destruction** within the firm
  - ▶ Automation **increases sales** and **induces business-stealing**
  - ▶ **No evidence** of an impact of automation on **average wage** or firm-level **wage inequality**

- IV analysis using shift-share design shows that automation:
  - ▶ Increases firm-level employment with an elasticity around 0.4% after 5 years
  - ▶ Increases firm-level sales with an elasticity around 0.35% after 5 years

This paper: Main Findings - Industry level

- Event studies:
  - Overall effect of automation on employment and sales remains positive at industry-level

- Shift-share IV:
  - Positive causal effect of automation on employment and sales at industry level

- OLS:
  - Positive relationship between automation and employment is driven by industries that are exposed to international trade

Literature

- Labor Market / Industry-level studies find mixed results

  - Industrial robots: Acemoglu and Restrepo 2019, Michaels and Graetz 2018, Dauth et al. 2021

- Automation (patents): Dechezleprêtre et al. 2021, Mann and Puttmann 2020

- Recent/ongoing work studies robots at firm level

  - Acemoglu et al. 2020, Bonfiglioli et al. 2020, Bessen et al. 2019, Chandler and Webb 2019, Dixon et al. 2019, Humlum 2019, Koch et al. 2019

    - ★ Emerging empirical consensus of a positive association between robots and employment at firm level

  - Relative to these studies, we can:

    - ★ Consider broader set of automation technologies
    - ★ Use shift-share design to estimate causal effects of automation on employment and other variables, both at firm and industry levels

Roadmap

1 **Data and measurement**

2 Event studies

3 Shift-Share IV

4 Industry-level Analysis

Data: Worker/Firm Data

- Detailed information on workers and firms available from French administrative data

  - Matched employer-employee data (DADS) and balance sheet data (Ficus/Fare) covering all firms in French manufacturing industry from 1995 to 2017

  - Firms: employment, sales, industry, etc.

  - Workers: wages, occupation

Data: Measuring Automation

- Automation defined as the *"class of **electro-mechanical** devices that are relatively self-operating after they have been set in motion on the basis of predetermined instructions or procedures"* (Encyclopaedia Britannica, 2015)

Data: Measuring Automation

- Measuring automation:

  - **First measure: Motive power for motors used in production process**

    - Distinguishes between (i) motive power, (ii) thermic/thermodynamic uses (heating, cooling), and (iii) other uses (electrolysis, servers, etc.)

  - **Second measure: Balance sheet value of industrial machines**

    - Distinguishes between (i) industrial machines, (ii) land, (iii) buildings and (iv) others (IT, office equipment, etc.)

  - **Third measure: Imported specific CN8 industrial machines**

    - Machines found in categories HS84 and HS85
    - We exclude household machines (for cooking, washing, cleaning, etc), agricultural machines, lifts and escalators, IT machines, etc.
    - This measure is restricted to importing French firms
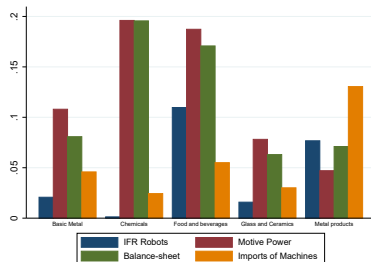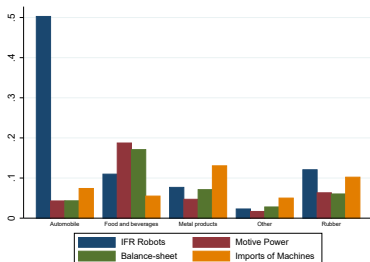
Examples

(a) Chemicals   (b) Paper   (c) Food

Data: Measuring Automation

- Advantages:
  - ▶ Covers broader set of automation technologies than IFR definition of an industrial robot, i.e. an "automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes" (ISO 8373)

Roadmap

Event studies

- **Question:** when a firm relies more extensively on automation, what happens to **employment**, **sales** and **prices**?

- Implementation of *event studies*:

  - **Extensive margin:** Event defined as a major investment in automation technologies a given year

  - **Intensive margin (distributed lead-lag model):** year-to-year evolution of automation

Event studies: Specifications

- Extensive margin:

$$log L_{it} = \alpha + \sum_{k=-n}^{n} \beta_k \mathbb{1}_{t-E_i=k} \mathbb{1}_{Invest_i > p_X(Invest)} + \mu_i + \lambda_{st} + \varepsilon_{it}$$
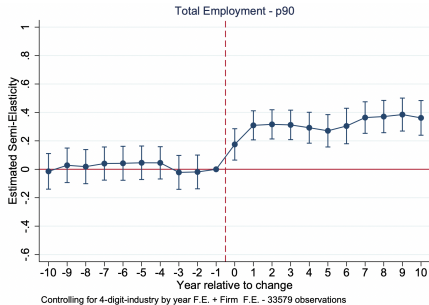
- Intensive margin:

$$log L_{it} = \alpha + \sum_{k=0}^{n} \delta_k^{Lag} \Delta log M_{i,t+k} + \sum_{k=1}^{n} \delta_k^{Lead} \Delta log M_{i,t-k} + \mu_i + \lambda_{st} + \varepsilon_{it}$$
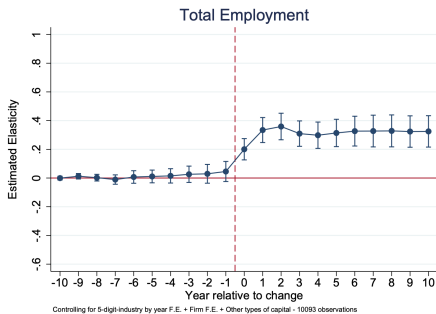
with employment L_{it}, change in machines $\Delta log M_{i,t}$, firm F.E. μ_i and industry-year F.E. λ_{st} (mitigate potential correlated shocks)

- Specification allows for delayed response of employment to increased automation
- Pre-trends (leads) can be used as a falsification test
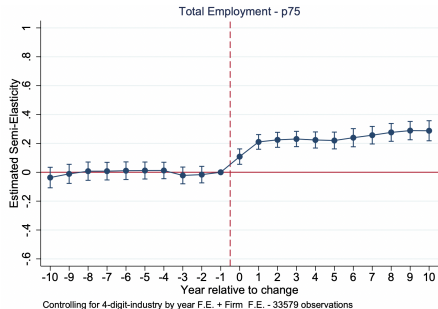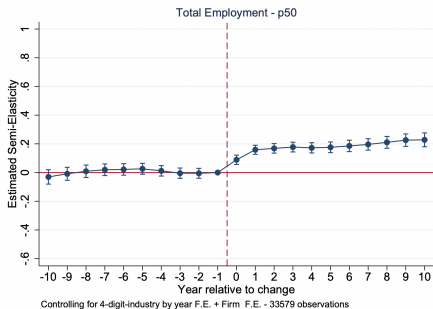
Event studies: Employment

(a) Extensive margin

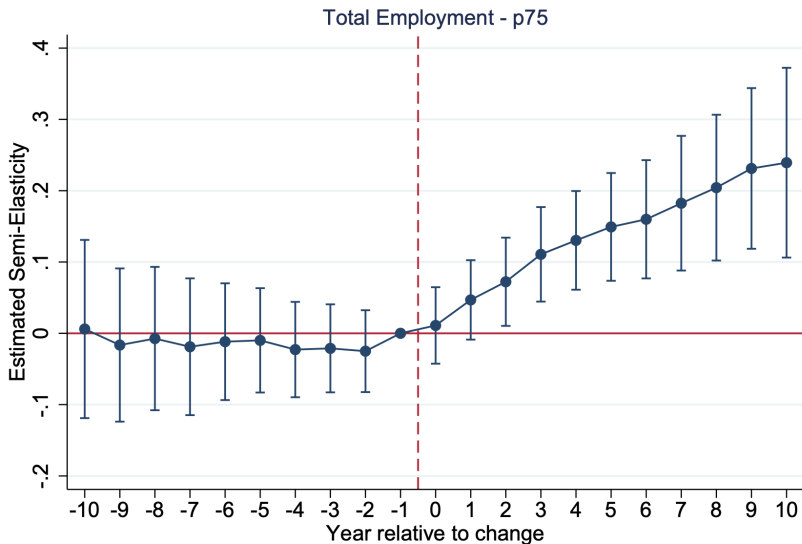(b) Intensive margin

Event studies: Employment - Robustness on event threshold

Event studies: Employment - Imports of industrial machines

Total Employment - p75

Controlling for 4-digit-industry by year F.E. + Firm F.E. - 7917 observations

Event studies: Employment - Motive Power

Total Employment - Motive power
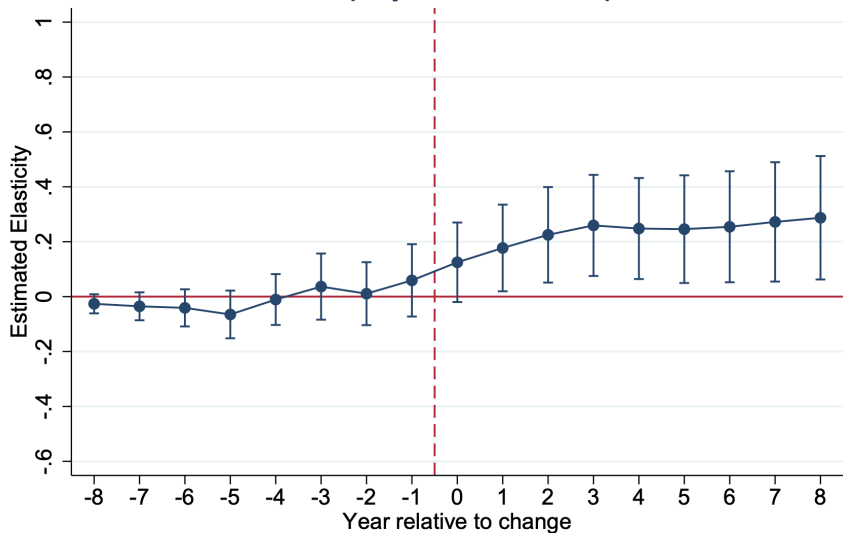
Controlling for 5-digit-industry by year F.E. + Firm F.E. - 2147 observations

Event studies: Employment - Automobile industry

Total Employment - p75
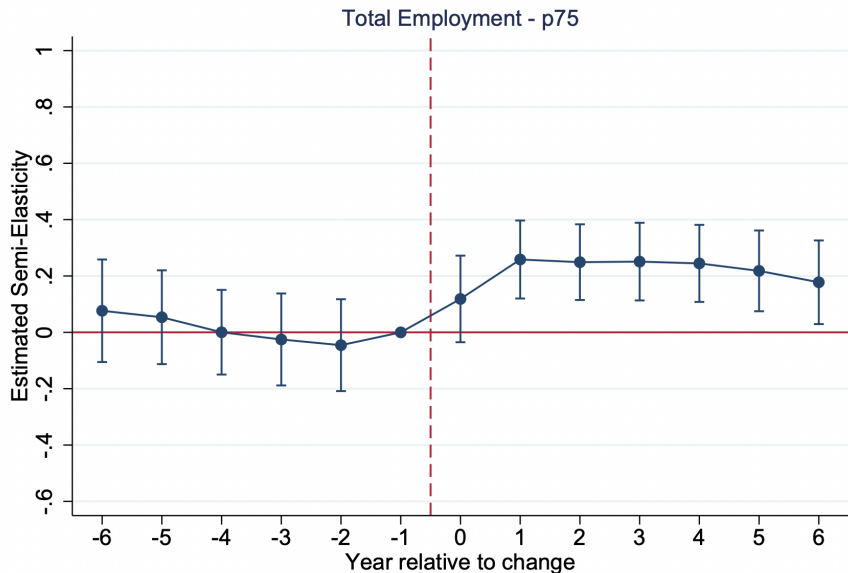
Controlling for 4-digit-industry by year F.E. + Firm F.E. - 3328 observations

Event studies: Employment - Heterogeneity?
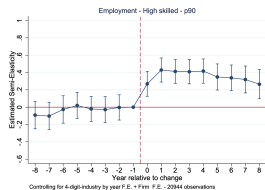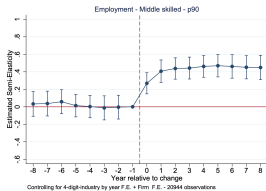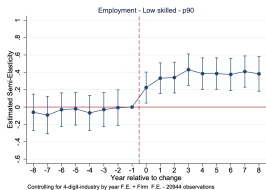
Event studies: Wage

Event studies: Job Creation & Job Destruction

Job creation - p90

Job destruction - p90

Job Dissimilarity Index
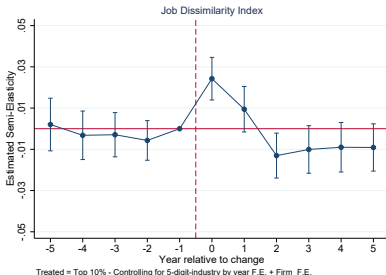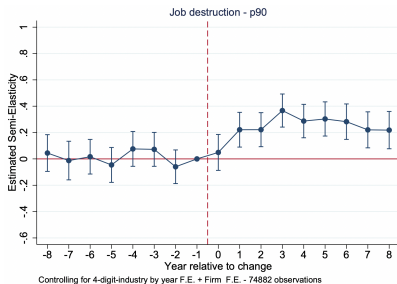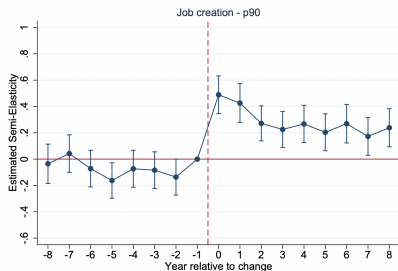
Event studies: Job Creation & Job Destruction
Placebo Test with Investments in Real Estate

Event studies: Prices

Export Price

Treated = Top 10% - Controlling for CN8-Product by year F.E. + Country by year F.E. + Firm F.E.

Event studies: Sales
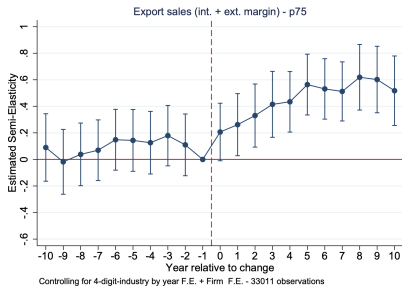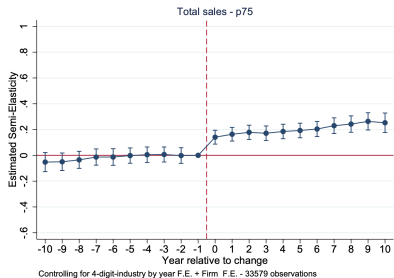
Total sales - p75

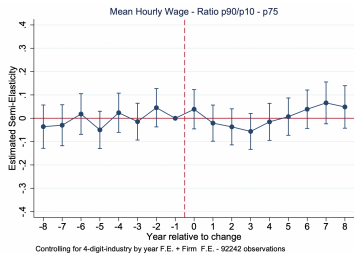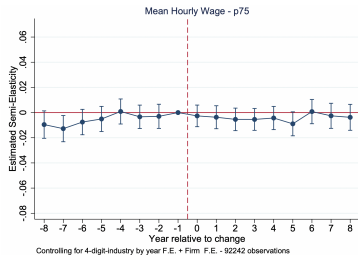Controlling for 4-digit-industry by year F.E. + Firm F.E. - 33579 observations

Export sales (int. + ext. margin) - p75

Controlling for 4-digit-industry by year F.E. + Firm F.E. - 33011 observations

Roadmap

Shift-Share IV

- Limitation: event studies cannot rule out potential demand/supply shocks in contemporaneous period

- Ideal experiment would randomly assign purchasing prices for machines across firms

- Approximate with a **shift-share research design**, leveraging two components:

    1. Variation in the cost of imported machines over time across international trading partners ("shocks")

    2. Variation in pre-existing supplier relationships across French firms ("exposure shares")

- Intuitively, **French firms are differentially exposed** to changes in sector-specific foreign productivity of **imported machines**

Shift-Share IV: Shocks

- **Shocks** are observed across trading partners by HS6 products:
  - We cannot directly observe changes in foreign machines' quality-adjusted prices
  - $g_{n,t}$ is change in imports flows of machines from each trading partners (Germany, Italy, China, etc.) for each HS6 product category into countries "similar to France" (EU $+$ Switzerland $-$ France) across 5-year periods

  $$g_{n,t} = \frac{ImportMachines_{n,t} - ImportMachines_{n,t-1}}{ImportMachines_{n,t} + ImportMachines_{n,t-1}}$$

  where n indexes "trading partner by HS6 product" cells
  - We only use HS6 codes corresponding to industrial machines

Shift-Share IV: Exposure Shares

- **Exposure shares** of French firms:
  - $s_{in,t}$ is share of trading partner n in firm i's total imports of machines in initial period (between 1995 and 1999)
  - Contemporaneous shares liable to reverse causality: use initial shares instead (and analyze outcomes from 2000 onward)
  - Because of switching costs, French firm more likely to benefit from a trading partner's productivity shock if it has a more important pre-existing importing relationship with them

Lenght of the relation between firm and main supplier
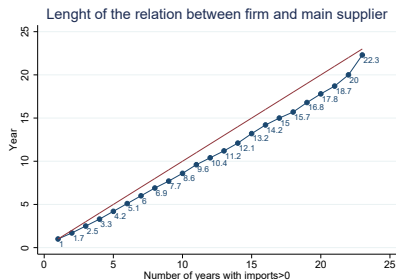
Shift-Share IV

- We estimate by 2SLS:

$$\begin{cases} \Delta L_{it} = \beta \Delta Z_{it} + \gamma X_{it} + \varepsilon_{it} \\ \Delta M_{it} = \alpha \Delta Z_{it} + \widetilde{\gamma} X_{it} + \widetilde{\varepsilon}_{it} \end{cases}$$

with Z_{it} the shift-share instrument constructed from shocks g_{nt} and (initial) exposure shares $s_{in} \geq 0$,

$$Z_{it} = \sum_{n=1}^{N} s_{in} g_{nt}$$

- Use panel with 5-year periods, 122 trading partners, and 196 HS6-products

Shift-Share IV: Identification Assumptions

- Relevance: need supplier relationships to be sufficiently persistent

  - Check power with first-stage F-statistic

  - Standard errors clustered by trading partner, which allows for correlated shocks within a trading partner over time and across products

- Exclusion restriction: firms linked to increasingly productive suppliers should not be unobservably different

  - Run falsification test with lagged outcome variable

Firm SSIV: First Stage

First Stage

Plot of 5-year Log Change in Industrial Equipment for Linked Firms against Instrument (foreign supplier productivity shock), with a fitted regression line.
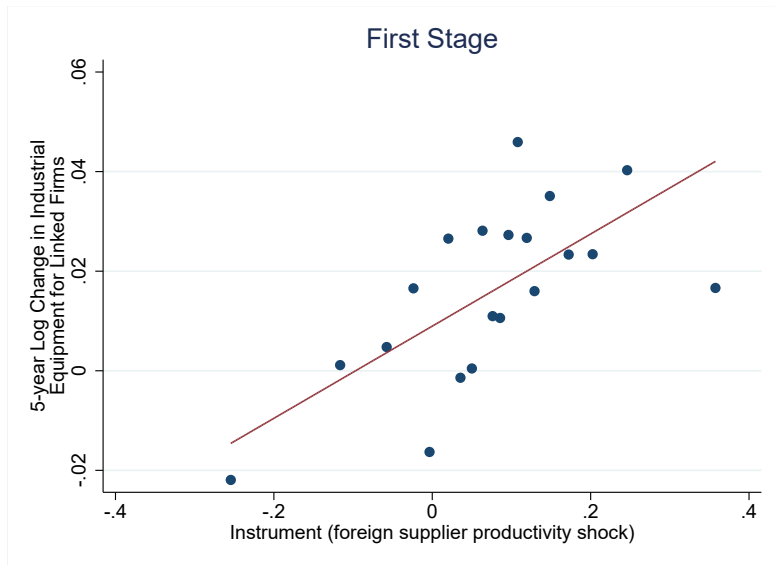
Firm SSIV: Reduced Form
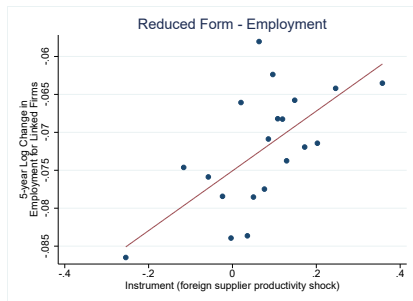
(a) Employment
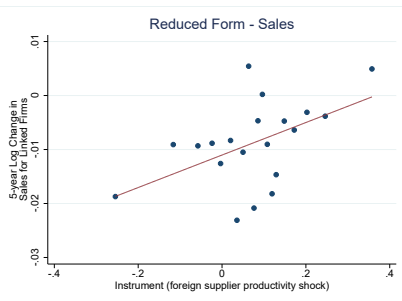
(b) Sales

Firm SSIV: Employment

	Δ_5 Employment				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**0.426*****	**0.425*****	**0.424*****	**0.433*****	**0.433*****
	(0.084)	(0.100)	(0.100)	(0.098)	(0.098)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product-period F.E.	✓	✓	✓	✓	✓
2-digit Industry-period F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Firm SSIV: Sales

	Δ_5 Sales				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**0.325*****	**0.340*****	**0.340*****	**0.345*****	**0.346*****
	(0.131)	(0.123)	(0.121)	(0.114)	(0.103)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product-period F.E.	✓	✓	✓	✓	✓
2-digit Industry-period F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Firm SSIV: Wages

	Δ_5 Hourly Wage				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**−0.0718***	**−0.0625**	**−0.0625**	**−0.0641**	**−0.0640**
	(0.0377)	(0.0390)	(0.0390)	(0.0395)	(0.0391)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Firm SSIV: Falsification Test - Lagged Employment

	Δ_5 Lagged Employment				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**−0.180**	**−0.198**	**−0.199**	**−0.199**	**−0.200**
	(0.219)	(0.220)	(0.223)	(0.220)	(0.218)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Firm SSIV: Falsification Test - Lagged Sales

	Δ_5 Lagged Sales				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**0.0274**	**0.166**	**0.165**	**0.155**	**0.155**
	(0.202)	(0.209)	(0.218)	(0.214)	(0.211)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Evidence of business stealing

Competitors Employment - p75
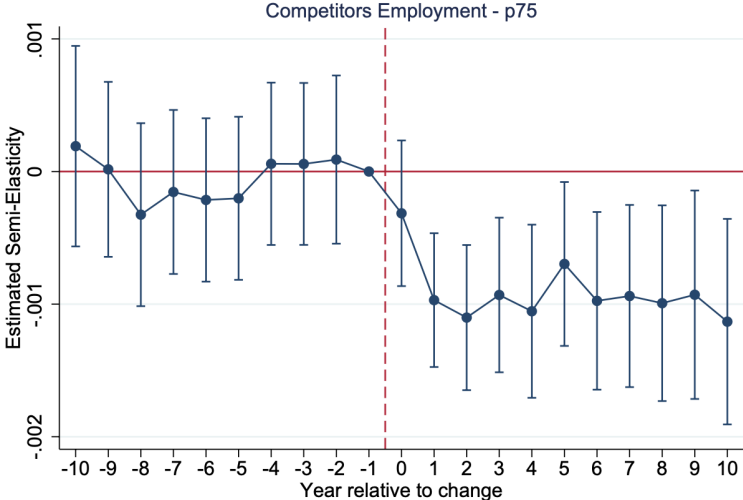
Controlling for 4-digit-industry by year F.E. + Firm F.E. - 33579 observations

Firm SSIV: Competitors' Employment

	Δ_5 Competitors' Employment				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	−**0.00578***	−**0.00920*****	−**0.00920*****	−**0.00914*****	−**0.00913*****
	(0.0032)	(0.0033)	(0.0032)	(0.0033)	(0.0033)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product-period F.E.	✓	✓	✓	✓	✓
2-digit Industry-period F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner-product-period)$	4,460	4,460	4,460	4,460	4,460

Roadmap

1. Data and measurement

2. Event studies

3. Shift-Share IV

4. **Industry-level Analysis**

Roadmap

1. Data and measurement

2. Event studies

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4. **Industry-level Analysis**

   1. **Event studies**

   2. Shift-Share IV

   3. OLS evidence on international business stealing

Industry Level Employment

Controlling for year F.E. + 5-digit Industry F.E.
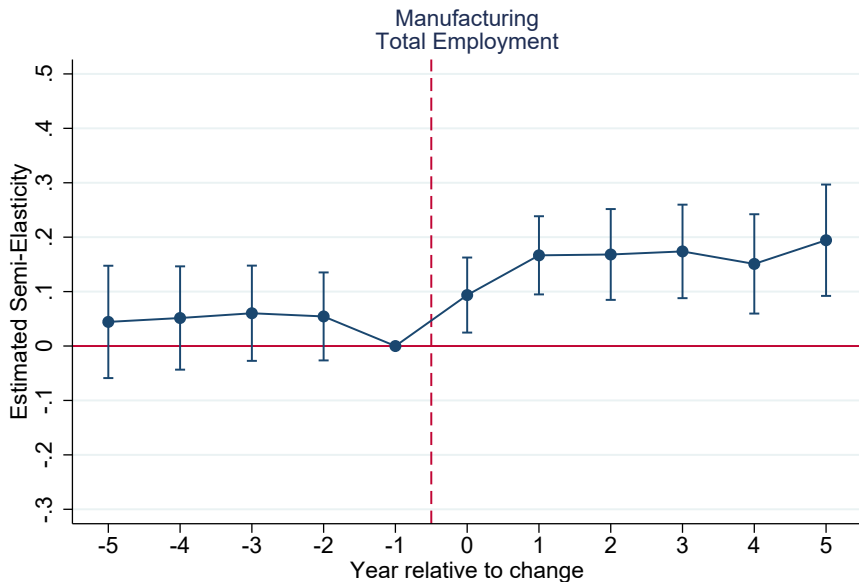
Industry Level Sales

Manufacturing
Total sales
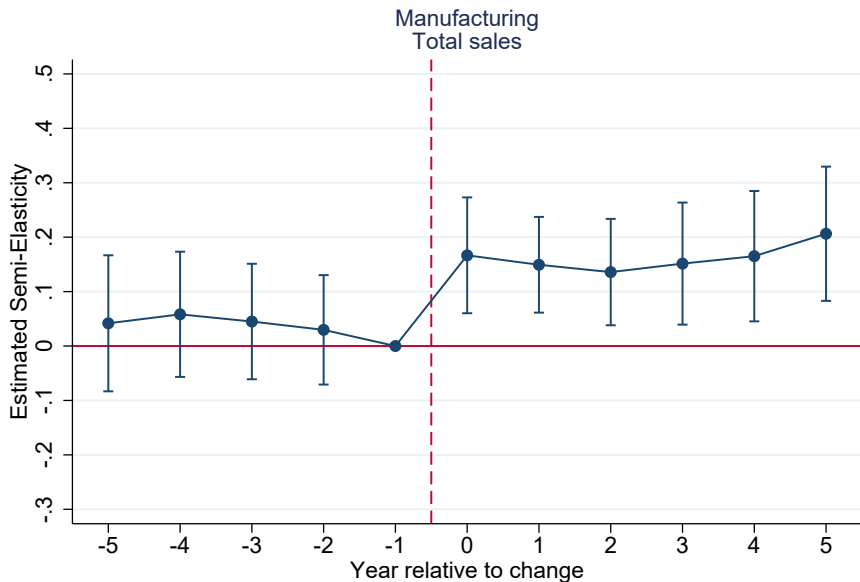
Controlling for year F.E. + 5-digit Industry F.E.

Industry Level Wages
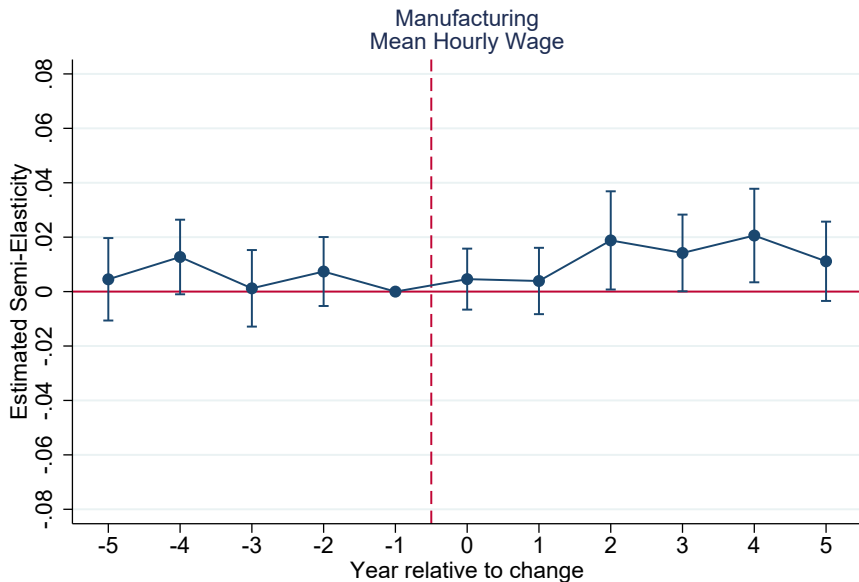
Controlling for year F.E. + 5-digit Industry F.E.

Industry Level Wage Inequality

Manufacturing
Mean Hourly Wage - Ratio Low/High Skilled
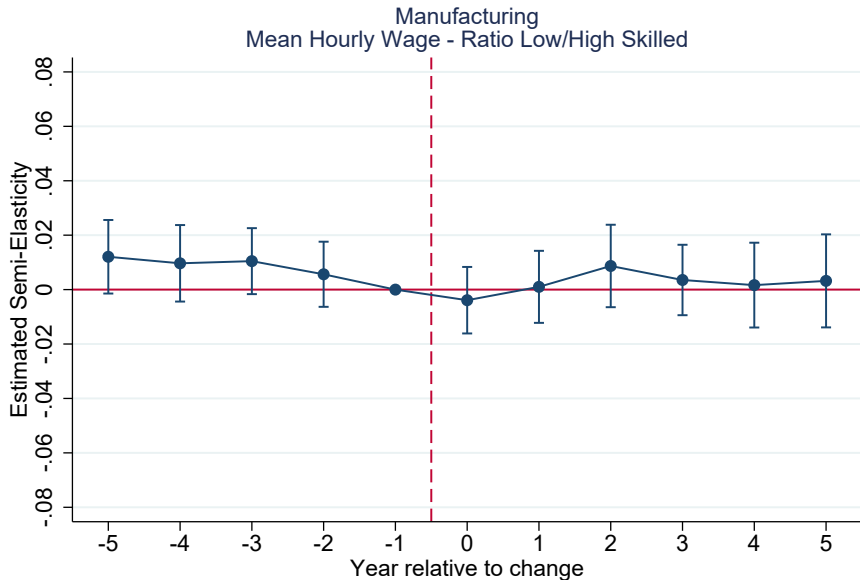
Controlling for year F.E. + 5-digit Industry F.E.

Roadmap

1. Data and measurement

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4. **Industry-level Analysis**

   1. Event studies

   2. **Shift-Share IV**

   3. OLS evidence on international business stealing

Industry Level SSIV

- Research design identical to firm-level SSIV, except that outcomes and initial shares are now measured at the industry level

  - We use the exact same trade shocks, measured across detailed HS6 product categories in the EU (excluding France) and Switzerland

  - Outcomes are measured at the level of 5-digit industries

Industry Level SSIV: Employment

	Δ_5 Employment			
	(1)	(2)	(3)	(4)
Δ_5 Machines	**1.080*****	**1.076*****	**1.081*****	**1.091*****
	(0.185)	(0.186)	(0.190)	(0.193)
First-Stage F	17.98	18.03	15.53	15.53
Partner-period F.E.	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓
Lagged Industry Controls	✓	✓	✓	✓
Lagged Machines		✓	✓	✓
Lagged Other Capital			✓	✓
Contemporaneous Exports				✓
$N(partner - product - period)$	7,687	7,687	7,687	7,687

Industry Level SSIV: Sales

	Δ_5 Sales			
	(1)	(2)	(3)	(4)
Δ_5 Machines	**1.309*****	**1.312*****	**1.245*****	**1.207*****
	(0.338)	(0.338)	(0.337)	(0.327)
First-Stage F	17.98	18.03	15.53	15.53
Partner-period F.E.	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓
Lagged Industry Controls	✓	✓	✓	✓
Lagged Machines		✓	✓	✓
Lagged Other Capital			✓	✓
Contemporaneous Exports				✓
$N(partner - product - period)$	7,687	7,687	7,687	7,687

Industry Level SSIV: Lagged Employment

	Δ_5 Lagged Employment			
	(1)	(2)	(3)	(4)
Δ_5 Machines	**−0.0318**	**−0.0176**	**−0.000564**	**0.0131**
	(0.249)	(0.251)	(0.261)	(0.260)
First-Stage F	17.98	18.03	15.53	15.53
Partner-period F.E.	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓
Lagged Industry Controls	✓	✓	✓	✓
Lagged Machines		✓	✓	✓
Lagged Other Capital			✓	✓
Contemporaneous Exports				✓
$N(partner - product - period)$	7,687	7,687	7,687	7,687

Industry Level SSIV: Lagged Sales

	Δ_5 Lagged Sales			
	(1)	(2)	(3)	(4)
Δ_5 Machines	**0.0811**	**0.0521**	**0.0442**	**0.0655**
	(0.264)	(0.257)	(0.271)	(0.268)
First-Stage F	17.98	18.03	15.53	15.53
Partner-period F.E.	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓
Lagged Industry Controls	✓	✓	✓	✓
Lagged Machines		✓	✓	✓
Lagged Other Capital			✓	✓
Contemporaneous Exports				✓
$N(partner - product - period)$	7,687	7,687	7,687	7,687

Roadmap

1. Data and measurement

2. Event studies

3. Shift-Share IV

4. **Industry-level Analysis**

   1. Event studies

   2. Shift-Share IV

   3. **OLS evidence on international business stealing**

Industry-Level Employment and International Competition

- International competition measured by share of imports in final consumption for each industry

	Δ Employment 1996-2017		
		International Competition	
	All Industries	Above Median	Below Median
	(1)	(2)	(3)
Δ Machines 1996-2017	**0.345*****	**0.404*****	**0.171**
	(0.059)	(0.055)	(0.133)
Δ Other types of capital 1996-2017	✓	✓	✓
N	255	121	134

Industry-Level Sales and International Competition

- International competition measured by share of imports in final consumption for each industry

	Δ Sales 1996-2017		
		International Competition	
	All Industries	Above Median	Below Median
	(1)	(2)	(3)
Δ Machines 1996-2017	**0.427*****	**0.510*****	**0.188**
	(0.066)	(0.084)	(0.121)
Δ Other types of capital 1996-2017	✓	✓	✓
N	255	121	134

Conclusion

- **Automation increases employment of firms that automate**, which indicates that in practice the productivity effect of automation on employment tends to outweigh the displacement effect

- Automation also **increases sales** and **profits**, and **reduces prices**
  - Hence overall **automation generates gains** that are **broadly shared** across workers, firm owners and consumers

- At **industry level** the relationship between automation and employment **remains positive on average**, but this is mainly driven by industries facing international competition

- Hence, particularly in a globalized world, **taxing robots** or other attempts to curb domestic automation **in order to protect domestic employment may be self-defeating**

Thank you!

simon.bunel@banque-france.fr

Data: Measuring Automation

Name	Value of Imports, €	Share of Imports
Apparatus for dry-etching patterns on semiconductor materials	430,688	0.0035
Bending, folding, straightening or flattening machines	675,899	0.0056
Letterpress printing machinery, reel fed (excl. flexographic printing machinery)	122,370	0.0010
Machine tools for working any material by removal of material, operated by electro-discharge processes	129,927	0.0010
Machines for butt welding of metals	28,319	0.00023
Machines for preparing textile fibres (excl. carding, combing, drawing or roving machines)	134,543	0.0011
Machines for processing reactive resins	30,259	0.00025
Machining centres for working metal (excl. horizontal machining centres)	2,194,883	0.018
Parts of machinery and apparatus for soldering, brazing, welding or surface tempering	197,589	0.0016
Printing machinery for use in the production of semiconductors	5,056	0.000042

The Employment Response for Unskilled Industrial Workers
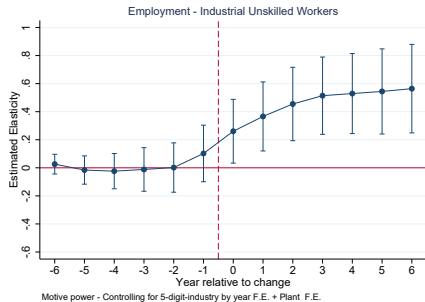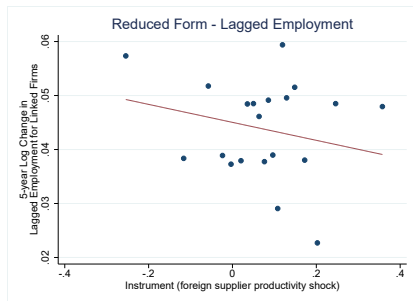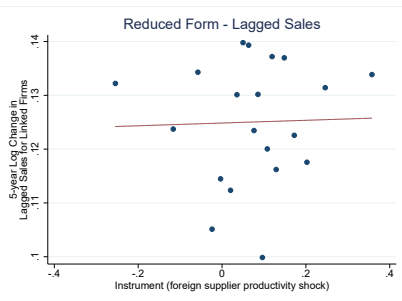

(a) Plant level (Distributed lag)
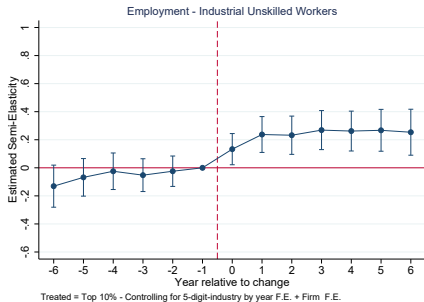
(b) Firm level (Event study)

Firm SSIV: Reduced Form

(a) Lagged Employment   (b) Lagged Sales

Firm SSIV: Profits

	Δ_5 Profits				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**0.995****	**0.824***	**0.824***	**0.827***	**0.828****
	(0.448)	(0.432)	(0.432)	(0.424)	(0.412)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product-period F.E.	✓	✓	✓	✓	✓
2-digit Industry-period F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
$N(partner - product - period)$	4,460	4,460	4,460	4,460	4,460

Firm SSIV: Labor Share

	Δ_5 Labor Share				
	(1)	(2)	(3)	(4)	(5)
Δ_5 Machines	**0.00453**	**0.00604**	**0.00607**	**0.00697**	**0.00686**
	(0.0164)	(0.0173)	(0.0172)	(0.0166)	(0.0157)
First-Stage F	17.65	20.59	21.43	20.88	21.62
Partner-period F.E.	✓	✓	✓	✓	✓
4-digit Product-period F.E.	✓	✓	✓	✓	✓
2-digit Industry-period F.E.	✓	✓	✓	✓	✓
Lagged Firm Controls		✓	✓	✓	✓
Lagged Machines			✓	✓	✓
Lagged Other Capital				✓	✓
Contemporaneous Exports					✓
N(partner − product − period)	4,460	4,460	4,460	4,460	4,460

Industry Level SSIV: Incumbents' Employment

	Δ_5 Employment			
	(1)	(2)	(3)	(4)
Δ_5 Machines	**0.608*****	**0.566*****	**0.583*****	**0.587*****
	(0.208)	(0.184)	(0.197)	(0.197)
First-Stage F	17.98	18.03	15.53	15.53
Partner-period F.E.	✓	✓	✓	✓
4-digit Product F.E.	✓	✓	✓	✓
Lagged Industry Controls	✓	✓	✓	✓
Lagged Machines		✓	✓	✓
Lagged Other Capital			✓	✓
Contemporaneous Exports				✓
$N(partner - product - period)$	7,687	7,687	7,687	7,687