Robot Imports and Firm-Level Outcomes

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Machines and Jobs: 1913

- in 1913 Ford introduces the integrated moving assembly line
  - man hours of final assembly dropped from more than 12 to fewer than 3

Machines and Jobs: Today

- where are the workers?

What We Do

- question:
  - how do *industrial robots* affect jobs and efficiency at the *firm level*?
- main challenges:
  - measure robot adoption
  - identifying causal effects
- this paper:
  - proxy for robot adoption: French firm-level imports of industrial robots
  - identification: new firm-level exposure to automation
    - available for non-importers too
  - study effect of robots on:
    - employment (across occupations), sales, productivity

What We Find

- robot adopters are larger, more productive and use more high-skill workers
- robot adoption accompanied by firm's scaling up
  - employment, sales and efficiency increase
- yet, net of demand shocks
  - efficiency *increases*
  - employment *falls* with robot adoption
- who gains/loses?
  - higher demand for high-skill workers (engineers & managers)
  - weak effects on total sales (higher profits?)

A Simple Model

- consider a firm with productivity φ_i facing demand: $y_i = A_i p_i^{-\sigma}$
- production function:
  - labor (l_i) and capital (k_i) performing a unit measure of tasks

$$y_i = \varphi_i \exp\left(\int_0^1 \ln x_i(z) \mathrm{d}z\right)$$

- problem of the firm:

$$\max_{k_i, l_i, \kappa_i} \left\{ p_i y_i - r k_i - w l_i - h f_i\left(\kappa_i\right) \right\}$$

  - κ_i = share of automated tasks $\longrightarrow$ performed by k_i as $r_i < w$
    - ⋆ convex cost of automation:

$$h f_i\left(\kappa_i\right) = h \frac{\rho_i}{1-\rho_i}\left[\left(1-\kappa_i\right)^{-\frac{1-\rho_i}{\rho_i}} - 1\right]$$

    - ⋆ $\rho_i \in (0,1)$: firm-specific "replaceability" of tasks

Demand for Labor and Automation

- automation and labor demand
  - combining the FOCs for l_i and k_i

$$\frac{d\ln l_i}{d\kappa_i} = \overbrace{(\sigma-1)\ln\left(\frac{w}{r_i}\right)}^{productivity} - \overbrace{(1-\kappa_i)^{-1}}^{displacement}$$

  - net effect may be positive for low κ_i and high σ
- endogenous automation
  - FOC for κ_i:

$$\frac{1}{1-\kappa_i} = \left[\left(1-\frac{1}{\sigma}\right)\frac{p_i y_i}{h}\ln\left(\frac{w}{r}\right)\right]^{\rho_i}$$

  - automation κ_i:
    - ★ increasing in scale (demand and productivity)
    - ★ increasing in cost-saving (w/r)
    - ★ especially in firms with high replaceability ρ_i

Identification Strategies

- threat to identification:
  - demand shocks affect employment both directly and through κ
    - regress l on $\kappa \longrightarrow$ upward bias
- strategy 1: robot intensity net of demand shocks
  - robot cost over capital expenditure

$$\frac{\kappa_i}{rk_i} = \frac{1}{hf_i'(\kappa_i)} \ln\left(\frac{w}{r}\right)$$

    - demand shocks affect robot cost and capital expenditure equally
- strategy 2: exogenous robot exposure
  - costs savings spur automation more in firms with more replaceable tasks ρ_i

$$\frac{1}{1-\kappa_i} = \left[\left(1 - \frac{1}{\sigma}\right) \frac{p_i y_i}{h} \ln\left(\frac{w}{r}\right)\right]^{\rho_i}$$

  - interact firm-specific replaceability $\times$ industry-level robot suitability

The Data

- near universe of French firms from 1994-2013
- balance-sheet data from BRN and FARE
  - sales, materials, capital stock (value of physical assets), employment
- full-time employment
  - at the plant level for 6 occupations from DADS etablissement (aggregated at the firm level)
  - 29 occupations in 1994
- imports and exports at the firm level
  - value and unit values by 8 digit CN code, from French Customs (DOUANES)
  - industrial robot imports: CN 84795000
- final sample:
  - 64,173 manufacturing firms, ≥ 10 employees, 765 robot adopters

Preliminary Evidence: Specifications

- main variables:
  - Y_{it} = log: sales, employment, VA per worker; share of skilled workers
  - $Adoption_{it} = 1$ since 1st year of robot import, 0 otherwise
  - $\ln RobInt_{it} = \ln \frac{RobStock_{it}}{CapStock_{it}} = \ln \frac{\text{sum of robot imports over time}}{CapStock_{it}}$
- specifications:
  - panel OLS:

$$Y_{it} = \alpha_i + \alpha_{jt} + \beta \cdot Adoption_{it} + \mathbf{X}'_{it} \cdot \gamma + \varepsilon_{it}$$

  - DiD event study:

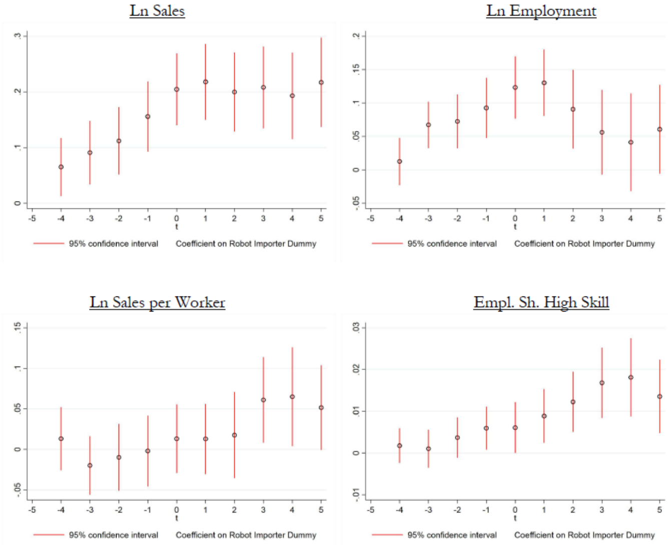
$$Y_{it} = \alpha_i + \alpha_{jt} + \sum_{s=-5}^{5} \beta_s \cdot Adoption_{it-s} + \varepsilon_{it}$$

  - i = firm, j = 5-digit industry, t = years
  - $\mathbf{X}'_{it}$ = initial log sales, importer & exporter status $\times$ year dummies
  - standard errors clustered by firm

Preliminary Evidence: Results

	(1)	(2)	(3)	(4)
	Ln Sales	Ln No. of Employees	Ln VA per Worker	Empl. Sh. High Skill
		a) Robot Adoption		
Adoption_{it}	0.230***	0.106***	0.057***	0.003
	[10.458]	[5.763]	[3.630]	[1.030]
Obs.	596,166	597,282	585,886	597,282
R2	0.95	0.87	0.85	0.70
		b) Robot Intensity		
Ln RobInt_{it}	-0.129***	-0.144***	0.040***	0.015***
	[-4.150]	[-5.427]	[2.654]	[2.815]
Obs.	5,706	5,711	5,542	5,711
R2	0.97	0.93	0.84	0.89

DiD Event Study



Identification: Robot Exposure

- exogenous firm-level exposure to robots:

$$RobExp_i = RobSuit_{j-i} \cdot Repl_i$$

  - firm-level replaceability of employment:

$$Repl_i = \sum_{o=1}^{29} \omega_{oi} \cdot Repl_o$$

    - ★ $Repl_o$ = replaceability of occupations (from Graetz & Michaels, 2018, mapped to French occupations)
    - ★ ω_{oi} = share of occupation o in firm i's employment in 1994

  - industry-level robot suitability:

$$RobSuit_{j-i} = \sinh^{-1}\left(\frac{\sum_{i' \neq i \in j} RobStock_{i'}}{\sum_{i' \neq i \in j} CapStock_{i'}}\right)$$

    - ★ initial robot intensity of 5-digit industry j (excluding firm i)

Specification: Long Differences

- robot exposure
  - long-differences:

$$\Delta Y_i = \alpha_j + \beta_1 \cdot RobExp_i + \beta_2 \cdot RobSuit_{j-i} + \beta_3 \cdot Repl_i + \mathbf{X}_i' \cdot \gamma + \varepsilon_i$$

  - ΔY_i = annualized change in firm i's outcome over the sample period
  - α_j = 5-digit industry fixed-effects (differential trends across industries)
  - $\mathbf{X}_i'$ = start-of-period firm characteristics (heterogeneous trends across firms)
  - standard errors clustered by firm
- β_1 identified from differences in the growth of outcomes across sectors and firms (diff-in-diff)

Robot Exposure: Main Results

	(1)	(2)	(3)	(4)	(5)
	Δ Ln Sales	Δ Ln No. of Employees	Δ Ln VA per Worker	Δ Empl. Sh. High Skill	Adopter
	a) Baseline Regressions				
$RobExp_i$	0.148	-0.094**	0.302***	0.006	0.174***
	[1.343]	[-2.095]	[2.702]	[1.106]	[2.893]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05

Robot Exposure: Robustness I

	(1)	(2)	(3)	(4)	(5)
	Δ Ln Sales	Δ Ln No. of Employees	Δ Ln VA per Worker	Δ Empl. Sh. High Skill	Adopter
			b) Weighted Regressions		
$RobExp_i$	0.142	-0.108**	0.310***	0.008	0.224***
	[1.192]	[-2.230]	[2.629]	[1.396]	[2.666]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.06	0.05	0.069
			c) Excluding Manufacturing of Motor Vehicles		
$RobExp_i$	0.148	-0.095**	0.303***	0.005	0.171***
	[1.329]	[-2.101]	[2.695]	[0.837]	[2.847]
Obs.	35,759	36,040	34,647	36,040	36,040
R2	0.10	0.04	0.07	0.04	0.052
			d) Broader Definition of Robot Imports		
$RobExp_i$	0.127	-0.038	0.187*	0.010**	0.261*
	[1.314]	[-0.810]	[1.768]	[2.096]	[1.830]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.11

Robot Exposure: Robustness II

	(1)	(2)	(3)	(4)	(5)
	Δ Ln Sales	Δ Ln No. of Employees	Δ Ln VA per Worker	Δ Empl. Sh. High Skill	Adopter
	e) Interactions with Demand Elasticity				
$RobExp_i$	-0.160	-0.203**	-0.061	0.001	0.065
	[-0.737]	[-2.020]	[-0.270]	[0.111]	[0.414]
$RobExp_i$ x $Elast_h$	0.069*	0.023	0.076*	0.002	0.023
	[1.963]	[1.405]	[1.955]	[0.774]	[0.838]
Obs.	32,427	32,679	31,365	32,679	32,679
R2	0.11	0.04	0.07	0.04	0.05
	f) Alternative Proxy for Robot Exposure (IFR)				
$RobExp_i$	3.331***	0.248	3.537***	0.070**	0.625***
	[9.669]	[1.043]	[11.543]	[2.537]	[3.469]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05

Robot Exposure: Identification Threats I

	(1)	(2)	(3)	(4)	(5)
	Δ Ln Sales	Δ Ln No. of Employees	Δ Ln VA per Worker	Δ Empl. Sh. High Skill	Adopter
	a) Interaction of Robot Suitability with Routine Intensity				
$RobExp_i$	0.151	-0.090**	0.297***	0.006	0.181***
	[1.385]	[-1.994]	[2.676]	[1.005]	[3.055]
$RobSuit_{j-i}$ x $Routine_i$	-2.934	4.864	9.589	1.193***	2.545
	[-0.129]	[0.829]	[0.433]	[2.781]	[0.355]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05
	b) Interactions of Robot Suitability with Firm Characteristics				
$RobExp_i$	0.137	-0.091**	0.283**	0.007	0.167***
	[1.260]	[-2.006]	[2.564]	[1.174]	[2.730]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05

Robot Exposure: Identification Threats II

	(1)	(2)	(3)	(4)	(5)
	Δ Ln Sales	Δ Ln No. of Employees	Δ Ln VA per Worker	Δ Empl. Sh. High Skill	Adopter
	c) Interactions of Replaceability with Firm Characteristics				
$RobExp_i$	0.148	-0.095**	0.304**	0.008	0.169***
	[1.245]	[-2.070]	[2.534]	[1.286]	[2.906]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05
	d) Interactions of Replaceability with Industry Characteristics				
$RobExp_i$	0.173	-0.137***	0.399***	0.012*	0.136**
	[1.591]	[-2.771]	[3.969]	[1.795]	[2.252]
Obs.	36,254	36,537	35,134	36,537	36,903
R2	0.10	0.04	0.07	0.04	0.05
	e) Interactions of Replaceability with Sector Dummies				
$RobExp_i$	0.155	-0.089*	0.306***	0.006	0.175***
	[1.353]	[-1.934]	[2.620]	[0.968]	[2.853]
Obs.	36,301	36,584	35,180	36,584	36,584
R2	0.10	0.04	0.07	0.04	0.05

Magnitudes

- compare firm with average $Repl_i$ in:
  1. manufacture of motor vehicles industry (high $RobSuit_{j-i}$)
  2. manufacture of wine industry (low $RobSuit_{j-i}$)
     - ⋆ 56% higher adoption probability in (1) vs (2)
     - ⋆ 0.30 p.p. per year larger employment fall in (1) vs (2)
- consider average increase in $RobSuit_{j-i}$ over 1994-2013, and compare:
  1. firm at 75th percentile of distribution by $Repl_i$
  2. firm at 25th percentile of distribution by $Repl_i$
     - ⋆ 48% higher adoption probability in (1) vs (2)
     - ⋆ 0.26 p.p. per year larger employment fall in (1) vs (2)

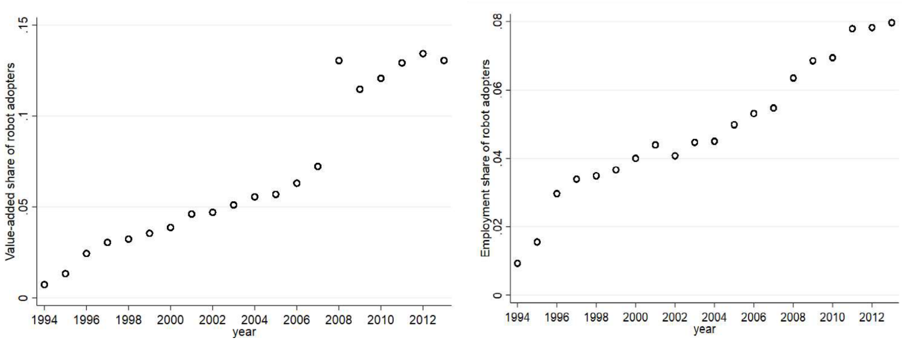
Conclusions

- first paper using a firm-level identification strategy to study the effect of robots
  - robot adoption and employment are correlated
  - but exogenous changes in automation lead to job losses
- displacement effect is large
  - important for labor demand and welfare
- automation increases productivity much more than sales
  - higher profits $\longrightarrow$ excessive automation?

Literature on Robots and Jobs

- theory:
  - Acemoglu & Restrepo (2018), Hemous & Olsen (2018), Zeira (1998)...
- empirics:
  - cross-industry studies: mixed results
    - Acemoglu & Restrepo (2019): IFR, US CZs, job loss
    - Graetz & Michaels (2018): IFR, 17 countries, higher productivity, no job loss
  - firm-level studies: correlations
    - survey data: EC (2015, 7 countries); Koch, Manuylov & Smolka (2019, Spain); Cheng et al. (2019, China), Dinlersoz & Wolf (2018, US)
    - import data: Humlum (2019), Dixen, Hong & Wu (2019), Acemoglu, Lelarge & Restrepo (2020)
  - firm-level studies: causality
    - Aghion et al. (2020, France): investment in machines and electricity raises employment
    - Bessen et al. (2019, Netherlands): third-party automation services increase separations

The Data: Robot Importers



- robot importers: 1% of all firms, but up to 15% of value added

Descriptive Stats: Robot Adopters vs. Non Adopters

	Obs.	No. Firms	Mean	Median	Std. Dev.	Mean Δ (annualized)
Robot Adopters						
Adoption	6,373	765	1	1	1	0
Robot Intensity	6,373	765	0.078	0.005	0.520	0.182
No. of Employees	6,373	765	852	191	3,129	-0.016
Empl. Sh. High Skill	6,373	765	0.153	0.108	0.142	0.006
Sales (€'000)	6,373	765	761,597	46,050	6,812,860	-0.075
Sales per Worker (€'000)	6,373	765	1,912	226	104,935	-0.061
VA per Worker (€'000)	6,225	761	178	65	2,715	-0.070
TFP	6,218	760	426	170	2,625	-0.066
Profits (€'000)	6,373	765	19,855	529	223,342	-0.052
Dummy Importer	6,373	765	0.972	1	0.164	0.001
Dummy Exporter	6,373	765	0.947	1	0.224	0.002
Export Price Index	6,039	750	242	22	2,045	0.014
Non Robot Adopters						
Adoption	598,925	63,408	0	0	0	0
Robot Intensity	586,785	63,448	0	0	0	0
No. of Employees	598,925	63,448	78	27	313	-0.030
Empl. Sh. High Skill	598,925	63,448	0.081	0.056	0.106	0.003
Sales (€'000)	598,922	63,448	54,703	7,615	683,130	-0.092
Sales per Worker (€'000)	598,922	63,448	666	231	11,725	-0.063
VA per Worker (€'000)	587,342	62,741	190	71	1,973	-0.066
TFP	576,404	62,005	292	132	1,362	-0.071
Profits (€'000)	598,925	57,293	1,256	98	36,795	-0.065
Dummy Importer	598,925	63,448	0.568	1	0.495	0.001
Dummy Exporter	598,925	63,448	0.561	1	0.496	0.004
Export Price Index	335,886	42,346	280	14	16,844	0.012