Robots and Jobs: Evidence from US Labor Markets

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Outline

This paper: Acemoglu and Restrepo (2017)

- Do robots increase or reduce employment and wages?
- Model with two main assumptions:
  - Labor and robots are perfect substitutes
  - Local labor markets exist in autarky
- In that case, (IV) regressions are enough
- Relax the second assumption: account for trade
  - Now need to calibrate some model parameters
- Conclusion: robots reduce both employment and wages

From different authors (for a different country):

- Dauth, Findeisen, Südekum, and Woessner (2017): German Robots - The Impact of Industrial Robots on Workers

From the same authors (with the same framework):

- Acemoglu and Restrepo (2016): The Race Between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment

Data and definitions

- What are robots?
  - International Federation of Robotics (IFR): "An automatically controlled, reprogrammable, and multipurpose [machine]"
  - Anything dedicated (suited for only one application) is also excluded (e.g. warehouse storage and retrieval)
- Where are robots (such defined)?
  - Automotive (39%), electronics (19%), metal products (9%), plastic and chemical industry (9%)
  - Place and time: see hereafter
- Data on robots
  - IFR started collecting numbers for Western European economies in 1993 (Denmark, Finland, France, Germany, Italy, Norway, Spain, Sweden, UK)
  - Same for United States in 2004
  - These data are *at industry level*
  - Combine with employment numbers to calculate: robots per worker

Empirics: the ascent of robots

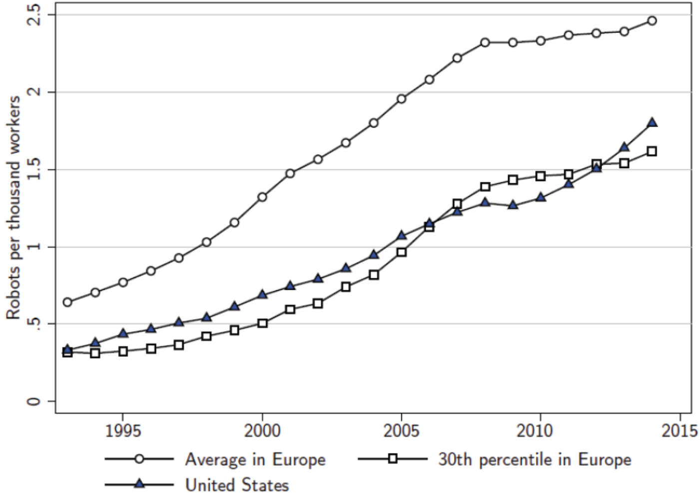
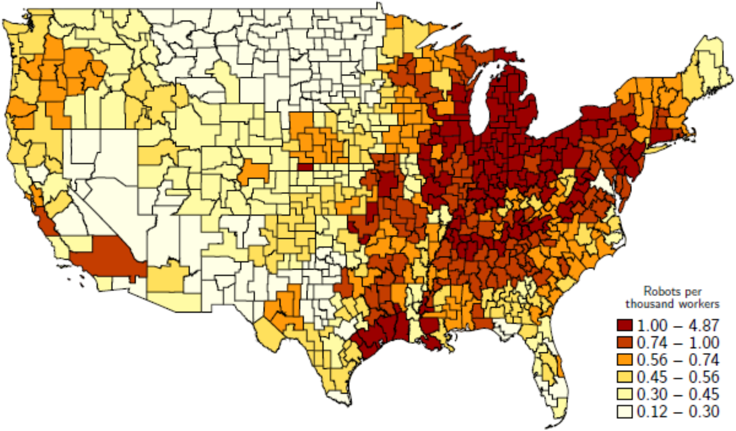


FIGURE 1: INDUSTRIAL ROBOTS IN THE UNITED STATES AND EUROPE.

Note: Industrial robots per thousand workers in the United States and Europe. Data from the International Federation of Robotics (IFR).

Empirics: geographic variation

A. Exogenous exposure to robots from 1993 to 2007



- Constructed data: industry level data on robots, commuting zone level data on industry shares
- 'Exogenous' means instrumented by European robot use data

Autarky Model: consumption

- Commuting zones c, industries i
- Preferences of a commuting zone

$$Y_c = \left(\sum_{i \in \mathcal{I}} \alpha_i Y_{ci}^{\frac{\sigma}{\sigma-1}} \right)^{\frac{\sigma-1}{\sigma}} \quad (1)$$

- σ elasticity of substitution across goods (industries), shares $\sum_{i \in \mathcal{I}} \alpha_i = 1$
- Autarky: production X_{ci} and

$$Y_{ci} = X_{ci} \quad (2)$$

Autarky Model: production

- Production of each good requires tasks $x_{ci}(s)$ indexed $s \in [0, S]$

$$X_{ci} = A_{ci} \min_{s \in [0,S]} \{x_{ci}(s)\} \tag{3}$$

- NB: There are no choices here, this is a Leontief!
- Each task also has a production function, form depends on technology frontier $M_i \in [0, S]$:

$$x_{ci}(s) = \begin{cases} \gamma l_{ci}(s) + r_{ci}(s) & \text{if } s < M_i \\ \gamma l_{ci}(s) & \text{if } s \geq M_i \end{cases} \tag{4}$$

- $r_{ci}(s)$ are robots, perfect substitutes for labor
- γ is the relative productivity of labor

Autarky Model: labor and robot supply

- Labor L_c and robot supply R_c depend on wages and robot costs (W_c and Q_c) in some reduced form:

$$W_c = \mathcal{W}_c Y_c L_c^{\epsilon} \tag{5}$$

$$Q_c = \mathcal{Q}_c \left(\frac{R_c}{Y_c}\right)^{\eta} \tag{6}$$

- $1/\epsilon$ is Frisch elasticity of labor supply
- $1/\eta$ elasticity of robot supply, cost is convex in robots (e.g. due to limited supply of local 'integrators')
- Firms assumed competitive, prices P_{Xci} equal unit cost
- Equilibrium: firms maximize profits, both markets clear
- Key assumption: cost savings gain $\pi_c = 1 - \frac{Q_c \gamma}{W_c} > 0$ in all tasks, i.e. production is on technology frontier M_i

Autarky Model: results

- Partial equilibrium effect of automation:

$$d \ln L_c^d = -\sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} - \sigma \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Xci} + d \ln Y_c \qquad (7)$$

- where $\ell_{ci} = \frac{l_c i}{\sum_{i \in \mathcal{I}} l_{ci}}$
- = *displacement effect* (workers replaced) – *price-productivity effect* (industry expands) + *scale-productivity effect* (overall demand rises)
- General equilibrium version (not entirely in fundamentals!):

$$d \ln L_c = -\frac{1+\eta}{1+\epsilon} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} + \frac{1+\eta}{1+\epsilon} \pi_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{s_{icL}}{s_{cL}} \frac{dM_i}{1 - M_i} \quad (8)$$

- where s_{icL} is labor share of income
- = *displacement effect* (workers replaced) + *productivity effect*
- Similar for wages

Autarky Model: at $M \approx 0$

- Restating:

$$d\ln L_c = -\frac{1+\eta}{1+\epsilon}\sum_{i\in\mathcal{I}}\ell_{ci}\frac{dM_i}{1-M_i} + \frac{1+\eta}{1+\epsilon}\pi_c\sum_{i\in\mathcal{I}}\ell_{ci}\frac{s_{icL}}{s_{cL}}\frac{dM_i}{1-M_i} \quad (9)$$

- At $M \approx 0$:

$$\sum_{i\in\mathcal{I}}\ell_{ci}\frac{s_{icL}}{s_{cL}}\frac{dM_i}{1-M_i} \approx \sum_{i\in\mathcal{I}}\ell_{ci}\frac{dM_i}{1-M_i} \approx \frac{1}{\gamma}\sum_{i\in\mathcal{I}}\ell_{ci}\frac{dR_i}{L_i} \quad (10)$$

- Similar for wages
- Call the last term exposure to robots
- Empirically ($M \approx 0$ in 1990) we then have that:

$$d\ln L_c = \beta_c^L\sum_{i\in\mathcal{I}}\ell_{ci}\frac{dR_i}{L_i} + \epsilon_c^L \quad (11)$$

Channels (1/3)

What do increases in automation do to employment?

- Keynes famously predicted 'technological unemployment'
- Some preliminary remarks:
  - The model does not formally separate the intensive and extensive margins of labor supply - only relevant for overall labor supply, which is positively related to wages by assumption
  - The authors seem to think of this as 'extensive margin only'
  - SBTC: Any technological progress increases all wages
    - Simply a feature of (one good, one task, closed economy) CES production in competitive markets
    - No longer the case here
- There are many adjustment channel

Channels (2/3)

- Adjustment channels:
  1. Technology may be prohibitively expensive
     - Here: focus on robots that actually go into use
  2. A small drop in wages may make labor competitive again
     - Here: excluded, remain at frontier by assumption
  3. Technology may not be a perfect substitute, mitigates impact
     - Here: excluded, perfect substitute
  4. Technology has different complementarity with other tasks
     - Here: excluded
  5. Other tasks could absorb labor (wages would still fall)
     - Here: excluded, Leontief
  6. Other goods could absorb labor (wages would still fall)
     - Here: included
  7. Technology improves competitiveness in trade
     - Here: not yet included (but will be)
  8. Labor could migrate (wages would still fall?)
     - Here: excluded
  9. Income effect from increased productivity
     - Here: included

Channels (3/3)

What do increases in automation do to labor?

- Abstract from cost competition with labor (1,2) as would not see this in data
- Several missing channels (3-5, 8; 6 is included) would still see falling wages, but mitigate the effect
  - Of these, labor mobility (8) seems particularly pertinent
- Trade competitiveness and income effects from productivity (7 and 9) can turn the effect of robots around
  - Former (7) is included later, latter (9) is included

Emprical Approach

- Important to note: without belief in the theory, we could still investigate the effect of local *exposure to robots* on local employment and wages
- But: endogeneity issues plague the *exposure to robots* measure
  - Any number of things could have occurred in these sectors concurrently, influencing both employment and robots
- Authors deal with this in two ways
  - Use data on European robot-per-worker growth as an instrument
  - A battery of robustness checks for: broad industry composition, demographics, exposure to imports from China, from Mexico, capital stock growth, IT capital growth, decline in routine jobs, off-shoring of intermediate inputs, past trends in employment and wages
- Result: one more robot per thousand workers reduces aggregate employment to population by 0.37 percentage points (6 workers) and average wages by 0.73 percent
  - Results are robust for many different specifications

Trade Model

- Trade at no cost, prices X_{cdi}; market clearing now:

$$X_{ci} = \sum_{d \in \mathcal{C}} X_{cdi} \tag{12}$$

- Treat different origins as varieties (for internal solutions):

$$Y_{ci} = \left(\sum_{s \in \mathcal{C}} \theta_{si} X_{sci}^{\frac{\lambda-1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}} \tag{13}$$

- Assume $\lambda > \sigma$, $\sigma \geq 1$
- Equilibrium now further requires:

$$Y_c = \sum_{i \in \mathcal{I}} X_{ci} P_{Xci} \tag{14}$$

Trade Model: results

- Partial equilibrium:

$$d \ln L_c^d = -\sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} - \lambda \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Xci} + (\lambda - \sigma) \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Yi} + d \ln Y_c \tag{15}$$

- Industry advantage became greater than before (second term, $\lambda > \sigma$), but this is partially undone because robots also arrive elsewhere (third term)
- General equilibrium version is very involved, but depends on similar fundamentals as before

Trade Model: aggregation

- We want to have aggregate employment effects
- Under the assumption that $\pi_c = \pi$, and that $M_i = M \approx 0$, we have the following aggregate employment effects:

$$\frac{1+\eta}{1+\epsilon}(\pi - 1)\frac{1}{\gamma}\mathbb{E}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} \tag{16}$$

- Note that we are now taking averages over commuting zones
- No variation left to regress

Trade Model: calibrated parameters

- To calculate quantities, we now require estimates of fundamental parameters
- Regression estimates can still be connected to fundamental parameters
- Setting some of these with standard values from the literature, the remainder can be backed out
- π turns out to be the key parameter to which the results are sensitive
  - These are the cost savings from introducing robots
  - Calibrated on the basis of business consulting case studies
- Result: effect on employment 10% lower than local effect, effect on wages 30% lower; 0.13% increase in GDP from an extra robot per thousand workers

Conclusion

- Focuses on observable and new substitute for labor
- Employment $\neq$ welfare
- Theory highlights some of the relevant channels (but not all)
- Empirical strategy may identify local effects well
- Aggregated measurements may be sensitive to assumptions
- And to missing channels:
  - Gathmann, Helm, and Schönberg (2016) find that labor mobility shields German workers under 50 from employment losses due to mass layoffs
- Overall, the impression remains that this empirical question is hard to answer

Dauth, Findeisen, Südekum, and Woessner (2017): German Robots

- Do the (exact) same thing to estimate local effects in Germany, which is way more exposed to robots
- Find that local effects are zero - nothing to say on aggregates
  - Composition: two jobs disappear in manufacturing, get created in services
  - Wages fall overall, size is sensitive to controls but about half as large as the local effects in Acemoglu and Restrepo (2017)
  - Distribution: high skills gain, others loose
- Also look at firm aggregates at regional level, find robots cause(!?) declining labor share due to increased profits
- Have micro survey data on companies
  - Find that robot exposed have a higher probability of keeping their job
  - Smaller flow of entrants to these jobs
  - They attribute the difference to the US to unions' power, who care for full employment
- Let's look at automotive

Most (and many) robots arrive in automotive

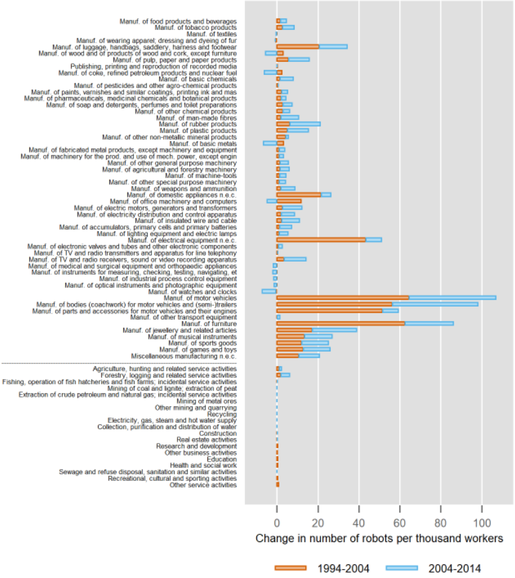


Figure 2: Industry-level distribution of robots

Automotive grows explosively due to emerging markets demand

- ‘Installed’ cars (meaning after some go out of circulation) grows at 4% per annum globally due to emerging markets demand
- Two-thirds of German automotive sales are for export
- High skilled workers for global production are in Germany: where the robots arrive is where the money is made (spillovers!)
- This is a global trend (just like, and concurrent with, robots) that the IV (other countries at industry level) cannot deal with
- Could this bias results upwards?
- Excluding the top two automobile locations, one robot replaces almost one worker (but not statistically significant)

Why would local effects be smaller in Germany?

- As noted, issues with global demand for certain products
- Also, think of robot arrival timing as a cost issue, instead of technology/innovation
  - The productivity effect is always zero in this case
  - Robots arrive sooner when they are cheaper,
    when labor is more expensive,
    when complementary skills are abundant (e.g. installation)
  - The more productive a robot (at given price) is when this condition is met, the more labor it (i.e. one robot) can replace
  - How much labor there is to replace depends on earlier productivity choices
- Could this be a relevant difference between the US and Germany?
- Distinction between the two ways of thinking about robot arrival may not be innocuous at all
  (for example when aggregating local effects)
- Germany and the US cannot be seen in isolation: all the action is in industries where they compete intensely - see Acemoglu and Restrepo (2017)!

Acemoglu and Restrepo (2016): The Race Between Machine and Man

- Most advanced version of the task-based model
- Main differences to this version:
  - Production does not happen at technological frontier M_i when labor is cheap
  - Not only the technological frontier M_i can move, but also the set of tasks:
    - New tasks are the most complex, and can only be performed by labor (until the technology frontier advances there)
- Introduce trade-off between advancing the set of tasks (using labor), or automating production (using capital)
- Former happens when labor is cheap and makes labor more expensive, latter vice versa
- Authors demonstrate some sufficient conditions for balanced growth path (with constant wage growth)
- Other results: on factor shares, welfare (model of innovation)

Literature I

Acemoglu, D. and P. Restrepo (2016). The race between machine and man: Implications of technology for growth, factor shares and employment. Technical report, National Bureau of Economic Research.

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