

Robots and Jobs: Evidence from US labor markets.

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Downward trends in employment and the labor share.

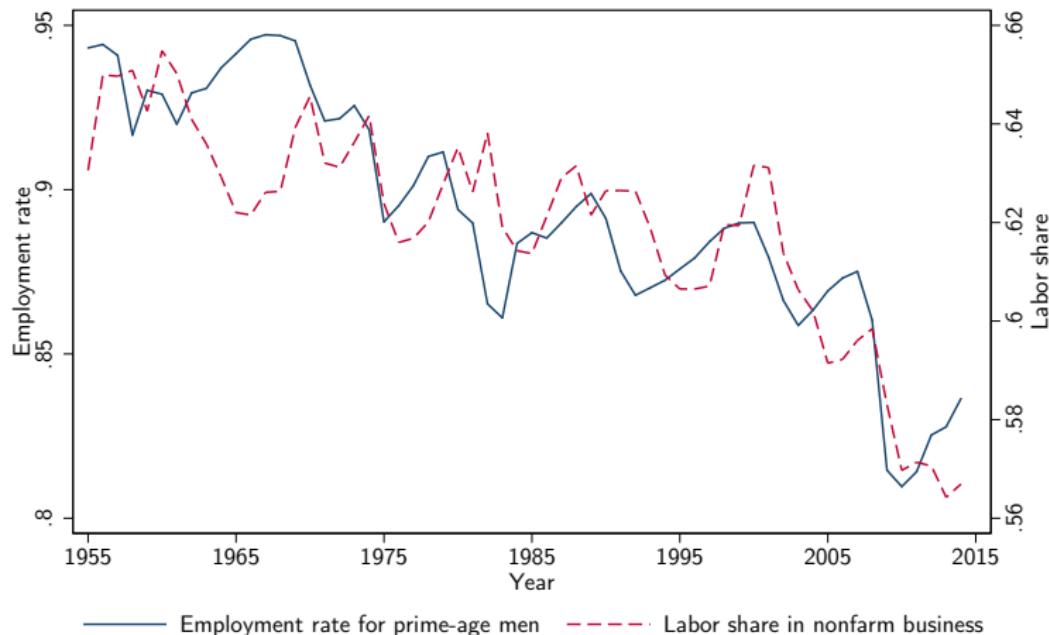


Figure: Trends in the U.S. nonfarm business sector labor share and employment to population ratio among men between 25-54 years. Data: BLS.

Is automation responsible?

Mounting evidence that automation affects labor markets:

- ▶ Wage inequality and employment polarization (Autor, Levy & Murnane, 2003; Michaels, Natraj & Van Reenen, 2014).
- ▶ Firms that use new technologies demand different skills (Bartel, Ichniowski, & Shaw, 2007).

It is (or will soon be) feasible to automate many jobs.

- ▶ In the next 20 years, 50% of US jobs could be automated (Frey & Osborne, 2013; World Bank, 2016).

But does automation reduce employment and wages **in equilibrium**?

This paper

We estimate the employment and wage effects of **industrial robots** on US labor markets.

- ▶ The International Federation of Robotics (IFR) defines them as:

“an automatically controlled, reprogrammable, and multipurpose [machine] that can be programmed in three or more axes for use in industrial applications”

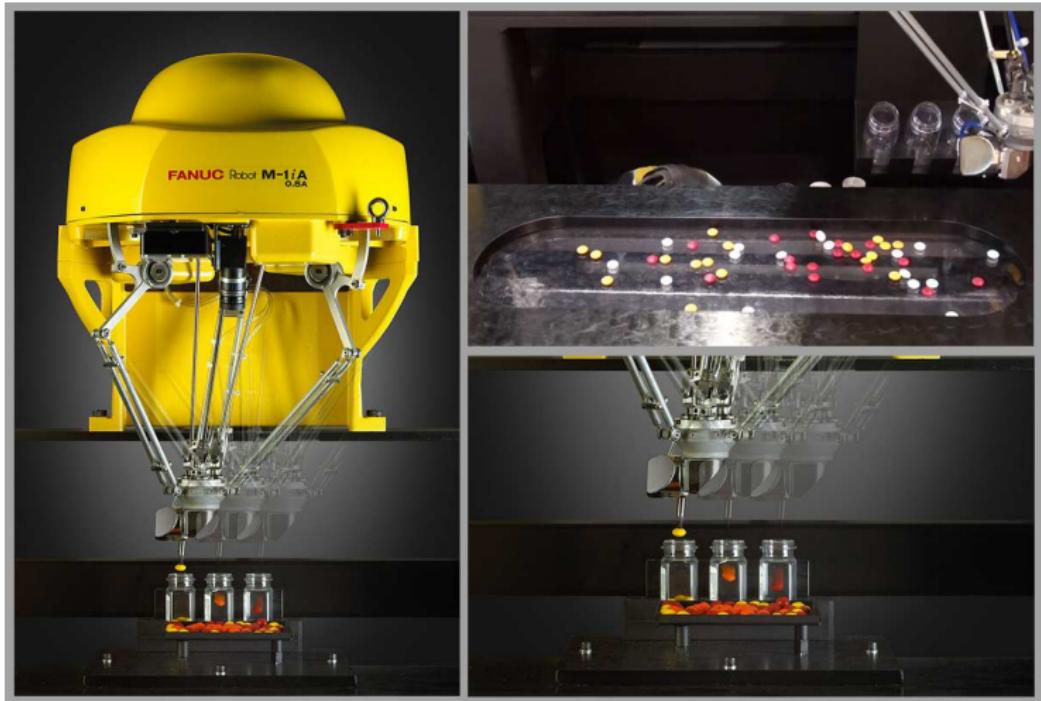
- ▶ Machines that do not need a human operator, and that can be programmed to perform several manual tasks such as welding, painting, assembling, sorting, handling materials, or packaging.

Industrial robots in car manufacturing



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@NUUNESTER

Industrial robots in the pharmaceutical industry



Industrial robots in food processing



Why focus on industrial robots?

Measurement and conceptual advantages:

- ▶ Unlike other forms of capital or technologies, industrial robots mostly replace—not complement—labor in the production of certain tasks.
- ▶ Comparable measure of robots across industries and countries.
- ▶ But it misses dedicated machines (ATMs, bending machines) and AGVs (Amazon warehouses)...

“The next big leap in manufacturing” (BCG 2016):

- ▶ Fourfold increase from 400,000 robots in 1993 to 1.75 million industrial robots in 2014.
- ▶ Already widespread in some manufacturing industries: automotive (39 percent); electronics (19 percent); metal products (9 percent); and plastic and chemicals (9 percent).
- ▶ Industrial robots expected to increase to 4.5-6 million by 2025.

The use of industrial robots

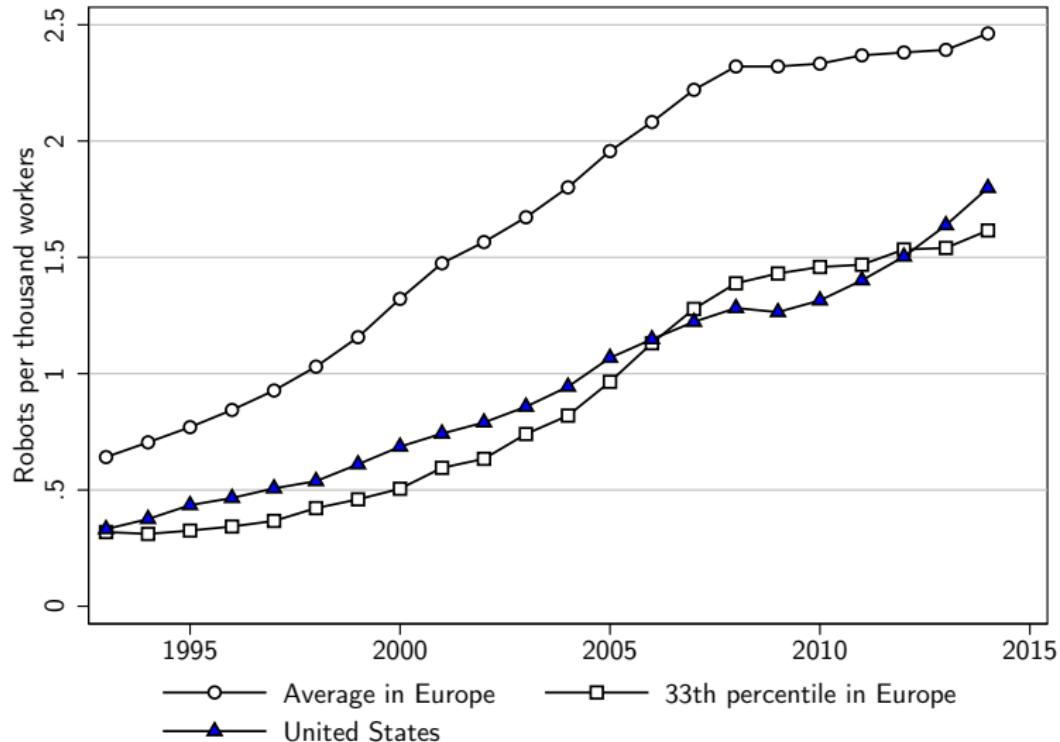


Figure: Trends in the use of industrial robots per thousand workers. Data: IFR.

What we do: theory

Model that clarifies why industrial robots may reduce employment and wages.

- ▶ Robots compete task-by-task against labor.
- ▶ Increase in the share of tasks performed by robots **displaces labor** from some tasks, but also **raises productivity**.
- ▶ Different from factor-augmenting techs, which always raise MPL.
- ▶ The net effect of industrial robots can be summarized by the change in exposure to robots:

$$\text{Change in exposure} \quad \begin{matrix} \text{to robots in a} \\ \text{local labor market} \end{matrix} = \sum_i \text{Base employment} \quad \times \quad \begin{matrix} \text{in industry } i \\ \text{in this market} \end{matrix} \quad \times \quad \begin{matrix} \text{National increase} \\ \text{in robots per} \\ \text{base workers in} \\ \text{industry } i. \end{matrix}$$

What we do: empirics

Measure the change in exposure to robots for US commuting zones from 1993 to 2007

- ▶ Data on the use of robots in 19 U.S. industries.
- ▶ Instrumented using comparable data for 9 European countries (as in Autor, Dorn and Hanson, 2013; and Bloom, Draca and Van Reenen, 2015).

$$\text{Change in exposure to robots in a local labor market} = \sum_i \text{Base employment in industry } i \text{ in this market} \times \text{National increase in robots per base workers in industry } i.$$

Findings

We estimate the impact of the change in exposure to robots from 1993 to 2007 on commuting zone outcomes

- ▶ Negative and significant impact on employment and wages.
- ▶ Unrelated to trends, concurrent technological changes or capital deepening across industries.
- ▶ Most affected: low-skilled men, routine-manual jobs, and manufacturing.

Large impact of one additional industrial robot

- ▶ One robot reduces employment by 7 jobs .
- ▶ One robot per thousand workers reduces wages by 1.6% .

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Large impact of one additional industrial robot

- ▶ One robot reduces employment by 7 jobs (**6.5 jobs once adjusted**).
- ▶ One robot per thousand workers reduces wages by 1.6% (**1.2% once adjusted**).
- ▶ Even if we adjust for the national gains through trade.

Aggregate implications

But the aggregate impact of industrial robots remains small

- ▶ From 1993 to 2007, US industries installed one additional robot per thousand workers.
- ▶ Robots explain 0.65 percentage points of the decline in employment.

Cautionary tale about the future

- ▶ From 2015 to 2025, US industries are expected to add 2.5 new robots per thousand workers.
- ▶ Could reduce employment by 1.75 p.p. and wages by 4%!
- ▶ **Key policy question:** how can we mitigate the negative impact of robots on employment and wages?

Related literature

Literature on the effects of technology on labor markets:

- ▶ Wage inequality (Katz & Murphy, 1992).
- ▶ Polarization (Autor, Levy & Murnane, 2003; Goos & Manning, 2007; Autor & Dorn, 2013; Michaels, Natraj & Van Reenen, 2014).
- ▶ Aggregate employment (Autor, Dorn & Hanson, 2015; Gregory, Salomons & Zierahn, 2016).

Empirical literature on industrial robots:

- ▶ Graetz & Michaels (2015): industries that adopted robots saw large productivity gains with some negative impact on low-skill employment.
- ▶ Green & Kraft (2015): geography of robot integrators in the US.

Outline for the rest of the talk

1. A model of industrial robots and jobs
2. Empirical specification and data
3. Results
4. Isolating the role of industrial robots
5. Incidence
6. Concluding remarks

1. A model of industrial robots and jobs

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A model of industrial robots and jobs

- ▶ We start with a model without trade.
- ▶ Several commuting zones indexed by the subscript $c \in \mathcal{C}$.
- ▶ Each commuting zone produces a final good Y_c by combining the output of several industries, which we index by the subscript $i \in \mathcal{I}$.
- ▶ The production technology for the final good Y_c takes the form:

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

with σ the elasticity of substitution

- ▶ α_{ci} is a share parameter designating the importance of industry i in commuting zone c .

Tasks and Production

- ▶ Each industry combines a continuum of tasks $s \in [0, 1]$.
- ▶ We denote by $x_{ci}(s)$ the quantity of task s utilized in the production of Y_{ci} . These tasks must be combined in fixed proportions:

$$Y_{ci} = B_i \min_{s \in [0,1]} \{x_{ci}(s)\}.$$

- ▶ In industry i tasks $[0, M_i]$ can be performed by robots, $r_{ci}(s)$; while the remaining tasks must be produced with labor, $l_{ci}(s)$:

$$x_{ci}(s) = \begin{cases} r_{ci}(s) + \gamma l_{ci}(s) & \text{if } s \leq M_i \\ \gamma l_{ci}(s) & \text{if } s > M_i, \end{cases}$$

- ▶ γ = productivity of labor; one robot produces the same as $\frac{1}{\gamma}$ workers.
- ▶ We assume robots are cheap; they produce all the tasks $s \leq M_i$.

Supplies and Market Clearing

- ▶ We specify the supply of robots and labor in each committing zone as follows

$$W_c = \mathcal{W}_c Y_c L_c^\varepsilon, \text{ with } \varepsilon \geq 0.$$

$$Q_c = \mathcal{Q}_c \left(\frac{R_c}{Y_c} \right)^\eta, \text{ with } \eta \geq 0,$$

- ▶ R_c is the total robots, L_c is the total amount of labor, Q_c is the price of robots, and W_c is the wage rate in commuting zone c .
- ▶ Market clearing then requires that

$$\sum_{i \in \mathcal{I}} \int_{[0,1]} l_{ci}(s) ds = L_c \quad \sum_{i \in \mathcal{I}} \int_{[0,1]} r_{ci}(s) ds = R_c.$$

Effect of Robots

Proposition

The effect of robots on employment and wages is given by

$$d \ln L_c^* = \frac{1+\eta}{1+\varepsilon} \frac{1}{s_{cL}} d \ln Y_c|_{R_c, L_c} - \frac{1}{\gamma} \frac{1+\eta}{1+\varepsilon} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}}$$
$$d \ln W_c^* = (1+\eta) \frac{1}{s_{cL}} d \ln Y_c|_{R_c, L_c} - \frac{1}{\gamma} \eta \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}},$$

where $\ell_{ci} = L_{ci}/L$ is the share of baseline total employment in commuting zone c that is in industry i , s_{cL} is the labor share, and

$$d \ln Y_c|_{R_c, L_c} = s_{cL} \frac{1}{\gamma} \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}} > 0$$

is the productivity effect—the impact of robots on commuting zone output holding the employment of labor and robots constant.

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Incorporating Trade

- ▶ As in Armington (1969), each Y_c is a differentiated good traded across commuting zones.
- ▶ National output is an aggregate of the goods produced in different commuting zones:

$$Y_N = \left(\sum_{c \in C} Y_c^{\frac{\sigma_N - 1}{\sigma_N}} \right)^{\frac{\sigma_N}{\sigma_N - 1}},$$

with σ_N the elasticity of substitution between these goods.

- ▶ We normalize the price of Y_N to 1. Thus, commuting zone prices are now given by

$$P_c = (Y_N/Y_c)^{\frac{1}{\sigma_N}}.$$

Incorporating Trade

Proposition

With trade, the effect of robots on employment and wages is given by

$$\begin{aligned} d \ln L_c^* &= \frac{1 + \eta}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{s_{cL}} d \ln Y_c|_{R_c, L_c} - \frac{1}{\gamma} \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}} \\ &\quad + \frac{\sigma/\sigma_N}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{s_{cL}} \sum_{c \in \mathcal{C}} s_c d \ln Y_c|_{R_c, L_c} \\ d \ln W_c^* &= \frac{(1 + \eta)(1 + \varepsilon)}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{s_{cL}} d \ln Y_c|_{R_c, L_c} - \frac{1}{\gamma} \frac{\eta(1 + \varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}} \\ &\quad + \frac{(\sigma\eta + 1)/\sigma_N}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{s_{cL}} \sum_{c \in \mathcal{C}} s_c d \ln Y_c|_{R_c, L_c} \end{aligned}$$

where $s_c = Y_c P_c / Y_N$, and

$$d \ln Y_c|_{R_c, L_c} = s_{cL} \frac{1}{\gamma} \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}} > 0$$

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Empirical Specification

- ▶ For $M_i \approx 0$, we can approximate

$$\sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{\Gamma_{iL}} \approx \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i}$$

- ▶ Thus, in both models we can estimate the effect of robots as:

$$d \ln L_c^* = \beta_c^L \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} + \epsilon_c^L \quad d \ln W_c^* = \beta_c^W \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} + \epsilon_c^W,$$

- ▶ In the model **without trade**, the random coefficients are given by

$$\begin{aligned}\beta_c^L &= \frac{1}{\gamma} \left[\frac{1+\eta}{1+\varepsilon} \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) - \frac{1+\eta}{1+\varepsilon} \right], \\ \beta_c^W &= \frac{1}{\gamma} \left[(1+\eta) \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) - \eta \right].\end{aligned}$$

Empirical Specification

- ▶ For $M_i \approx 0$, we can approximate

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- ▶ In the model **with trade**, the random coefficients are given by

$$\beta_c^L = \frac{1}{\gamma} \left[\frac{1 + \eta}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) - \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \right],$$

$$\beta_c^W = \frac{1}{\gamma} \left[\frac{(1 + \eta)(1 + \epsilon)}{1 + \epsilon + \frac{1}{\sigma_N s_{cL}}} \left(1 - \frac{Q_c^* \gamma}{W_c^*} \right) - \frac{\eta(1 + \varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \right].$$

Data

Data for 722 US commuting zones:

- ▶ Commuting zones \approx local labor markets.
- ▶ Census (or ACS) data for 722 commuting zones: employment, wages, and demographics for 1970, 1990, 2007.
- ▶ CBP data aggregated to the commuting zone level. Yearly from 1988-2014.
- ▶ Complemented with IRS data on income and nonwage income.

Measuring the change in exposure to robots

IFR data on robot use for 19 industries \mathcal{I} .

- ▶ Endogenous change in exposure to robots among US industries:

$$\text{endogenous change in exposure to robots, 2004-2007}_c = \sum_{i \in \mathcal{I}} \ell_{ci} \left[\frac{R_{i,2007}}{L_i} - \frac{R_{i,2004}}{L_i} \right].$$

- ▶ $\frac{R_{i,t}}{L_i}$ = robots per thousand workers that industry i employs in the US.
- ▶ Exogenous change in exposure to robots among US industries:

$$\text{exogenous change in exposure to robots, 1993-2007}_c = \sum_{i \in \mathcal{I}} \ell_{ci} \left[\frac{\overline{R_{i,2007}}}{\overline{L_i}} - \frac{\overline{R_{i,1993}}}{\overline{L_i}} \right].$$

- ▶ $\overline{\frac{R_{i,t}}{L_i}}$ = 33th percentile of the number of robots per thousand workers that industry i employs among European countries.
- ▶ Following the model, we measure the baseline employment share ℓ_{ci} in 1990—before the increase in robot usage.

Use of robots in the US vs Europe

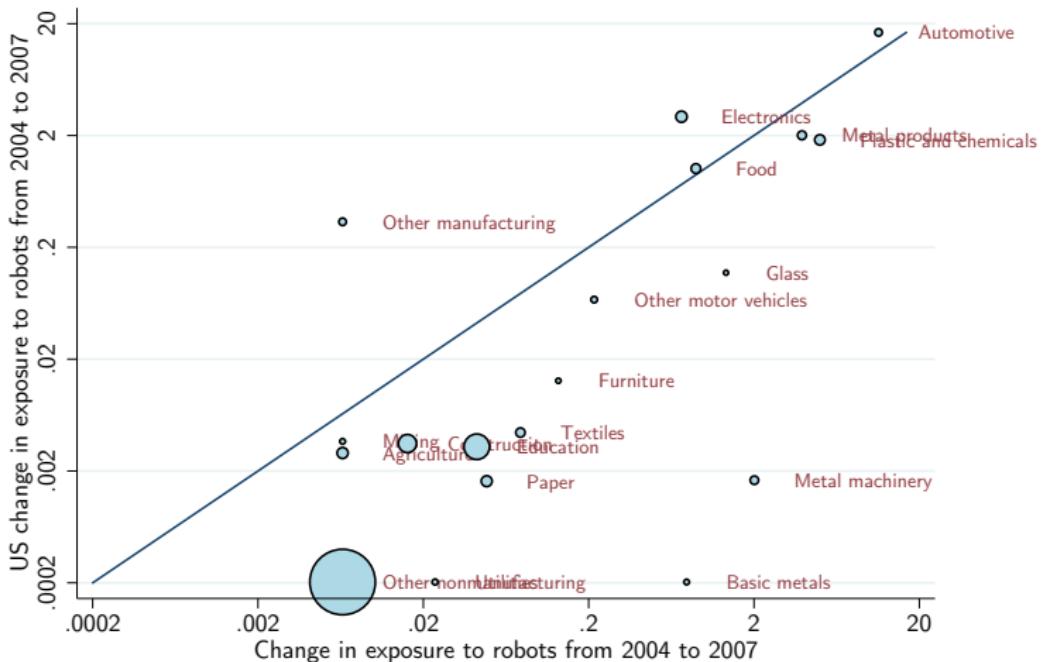


Figure: Change between 2004 and 2007 in the robot exposure for 19 different industries in the U.S. and Europe. Both axis are in a logarithmic scale.

First-stage relationship

$$\text{endogenous change in exposure to robots, } 2004-2007_c = \pi \cdot \text{exogenous change in exposure to robots, } 2004-2007_c + \nu_c.$$

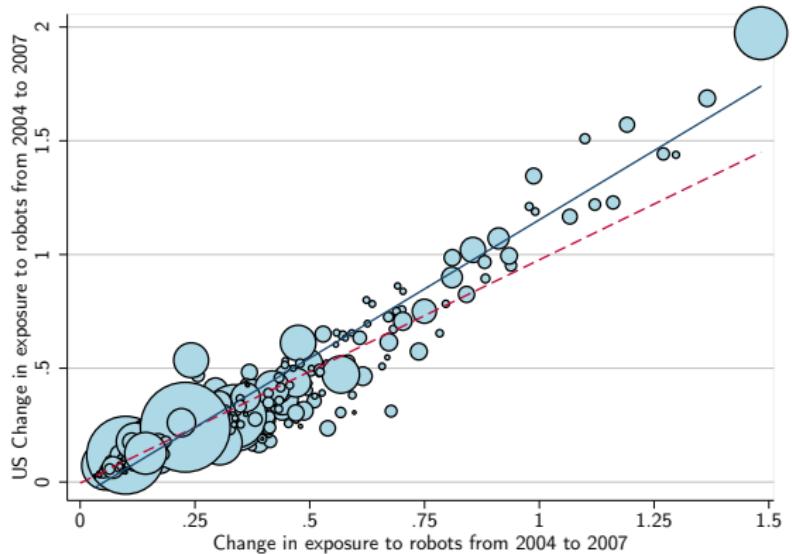
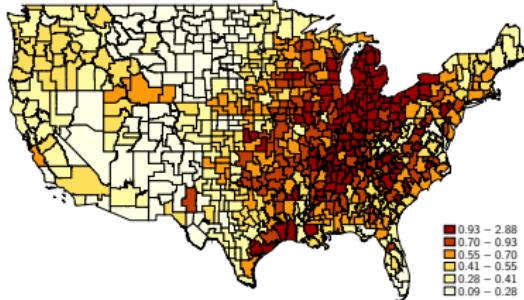


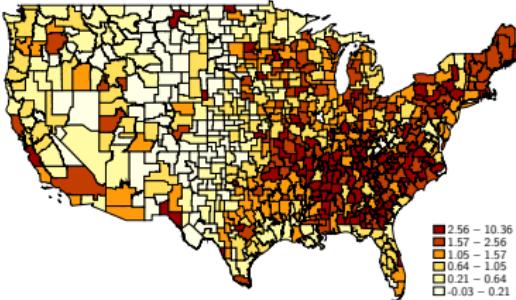
Figure: Commuting zones change between 2004 and 2007 in their endogenous and exogenous exposure to robots. $\hat{\rho}_i = 1.395$ (standard error=0.057).

Location of areas with the highest change in robot exposure and Chinese imports

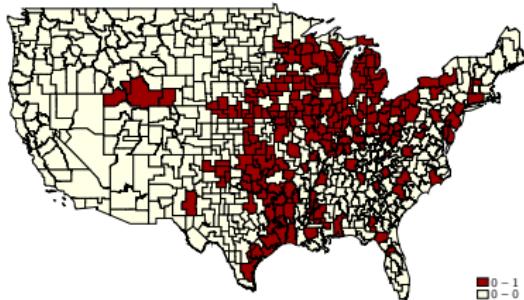
Change in exposure to robots from 1993 to 2007



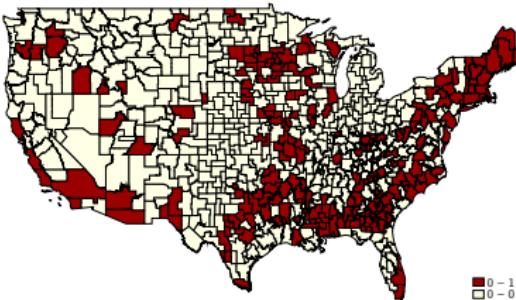
Exposure to Chinese imports from 1990 to 2007



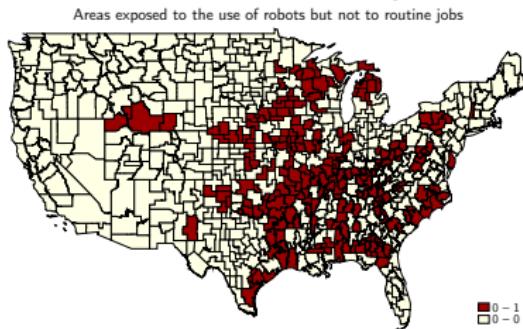
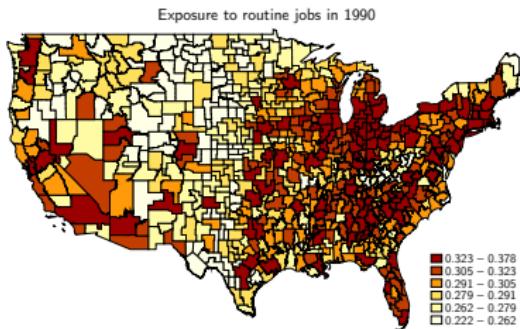
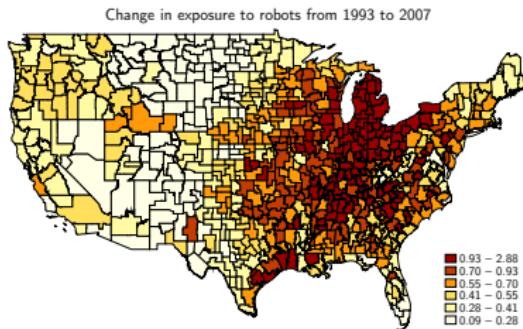
Areas exposed to the use of robots but not to Chinese imports



Areas exposed to Chinese imports but not to the use of robots



Location of areas with the highest change in robot exposure and routine (computerized) jobs



Summary statistics

Table: Summary Statistics: Outcome Variables

	ALL ZONES <i>N</i> = 722	QUARTILES OF THE CHANGE IN EXPOSURE TO ROBOTS			
		Q1 <i>N</i> = 180	Q2 <i>N</i> = 181	Q3 <i>N</i> = 180	Q4 <i>N</i> = 181
<i>Panel A. Outcomes</i>					
Employment to population ratio in 1990	0.381 [0.074]	0.353 [0.071]	0.395 [0.077]	0.388 [0.074]	0.389 [0.067]
Change in employment to population ratio from 1990 to 2007	0.020 [0.038]	0.034 [0.046]	0.010 [0.038]	0.021 [0.030]	0.014 [0.032]
Change of log employment from 1990 to 2007	0.232 [0.174]	0.347 [0.217]	0.229 [0.139]	0.213 [0.138]	0.140 [0.120]
Hourly wages in 1990	15.611 [2.492]	16.456 [3.002]	15.898 [2.308]	15.325 [2.339]	14.979 [2.261]
Change in the log of hourly wages from 1990 to 2007, adjusted for composition	-0.038 [0.046]	-0.024 [0.057]	-0.025 [0.047]	-0.042 [0.034]	-0.061 [0.035]

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Reduced-form estimates for employment, 1990-2007.

Table: Estimates of the change in exposure to robots on employment from 1990 to 2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census employment to population ratio.</i>						
Change in exposure to robots from 1993 to 2007	-0.013*** (0.005)	-0.012*** (0.003)	-0.010*** (0.002)	-0.010*** (0.002)	-0.011*** (0.003)	-0.015*** (0.005)
Observations	722	722	722	722	717	714
<i>Panel B. CBP employment to population ratio.</i>						
Change in exposure to robots from 1993 to 2007	-0.025** (0.010)	-0.021*** (0.005)	-0.017*** (0.005)	-0.016*** (0.005)	-0.009** (0.004)	-0.022** (0.010)
Observations	722	722	722	722	716	714
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	✓
Removes highly exposed areas						✓

Regression plot for employment, 1990-2007.

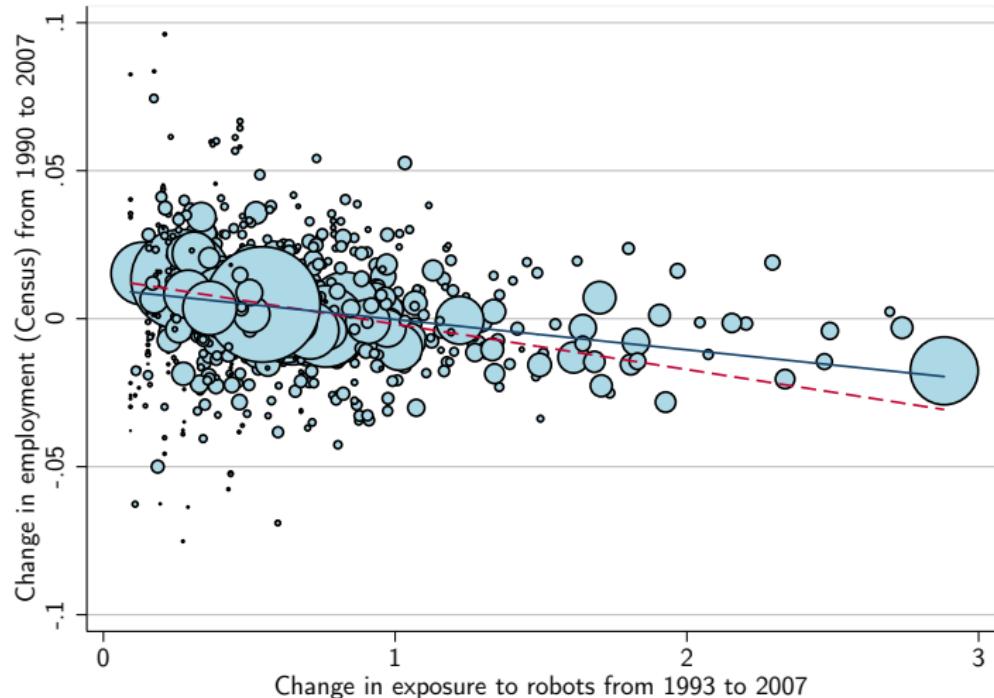


Figure: Regression plots for the impact of the change in exposure to robots on the Census employment to population rate.

Reduced-form estimates for wages, 1990-2007.

Table: Estimates of the change in exposure to robots on wages from 1990 to 2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. log of hourly wages</i>						
Change in exposure to robots from 1993 to 2007	-0.038*** (0.006)	-0.027*** (0.004)	-0.024*** (0.004)	-0.023*** (0.004)	-0.030*** (0.004)	-0.031*** (0.005)
Observations	163114	163114	163114	163114	159991	161042
<i>Panel B. log of weekly wages</i>						
Change in exposure to robots from 1993 to 2007	-0.050*** (0.007)	-0.039*** (0.004)	-0.035*** (0.004)	-0.034*** (0.004)	-0.034*** (0.005)	-0.039*** (0.006)
Observations	163114	163114	163114	163114	159671	161042
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

Regression plot for wages, 1990-2007.

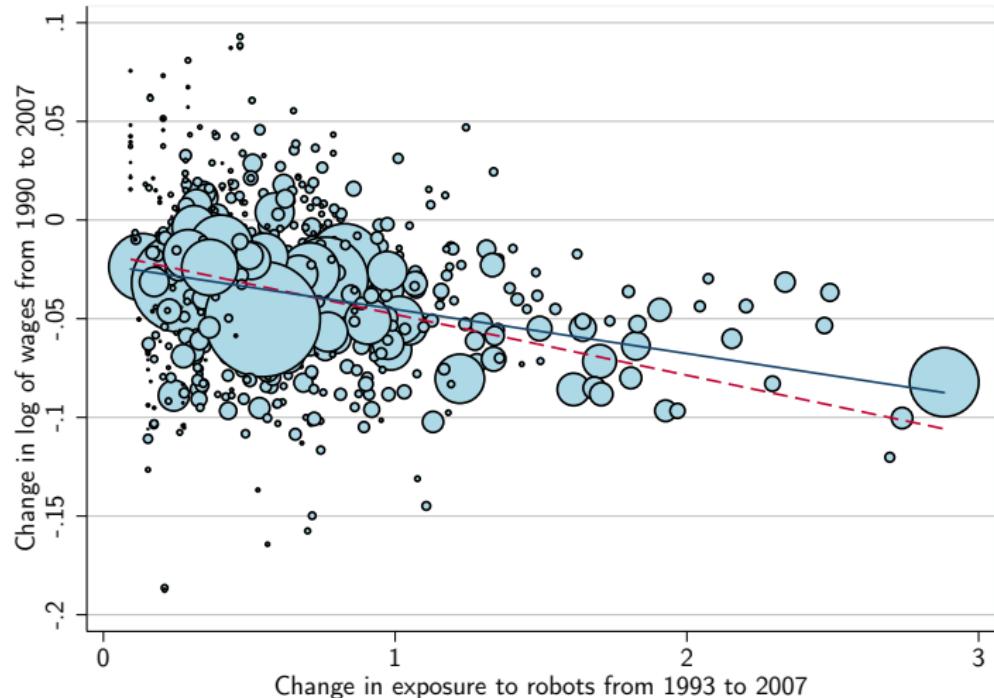


Figure: Regression plots for the impact of the change in exposure to robots on the log of hourly wages.

Two-sample IV estimates, 1990-2007.

Table: Two-sample IV estimates for employment and wages, 1990 to 2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. TSIV for the Census employment to population ratio.</i>						
Instrumented change in exposure to robots from 1993 to 2007	-0.010*** (0.004)	-0.009*** (0.002)	-0.007*** (0.002)	-0.007*** (0.002)	-0.009*** (0.002)	-0.013*** (0.005)
First-stage relationship	1.300*** (0.102)	1.391*** (0.056)	1.380*** (0.059)	1.395*** (0.057)	1.171*** (0.074)	1.148*** (0.079)
Observations	722	722	722	722	717	714
<i>Panel B. TSIV estimates for the log of hourly wages.</i>						
Instrumented change in exposure to robots from 1993 to 2007	-0.029*** (0.007)	-0.019*** (0.004)	-0.017*** (0.004)	-0.016*** (0.004)	-0.025*** (0.004)	-0.027*** (0.006)
First-stage relationship	1.301*** (0.101)	1.393*** (0.055)	1.380*** (0.059)	1.396*** (0.057)	1.221*** (0.091)	1.154*** (0.077)
Observations	206518	206518	206518	206518	159991	203873
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	✓
Removes highly exposed areas						✓

Quantitative implications

- ▶ From 1993 to 2007, in the US, robot exposure increased by one robot per thousand workers.
- ▶ Without trade, aggregate employment and wage effects of robots can be computed as follows:

$$\text{Employment loss} = \widehat{\beta^L} \cdot \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 0.07 \times 1 = 0.7\text{p.p.}$$

$$\text{Wage loss} = \widehat{\beta^W} \cdot \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 1.6\% \times 1 = 1.6\%.$$

- ▶ In the US, from 1990 to 2007, robots reduced the employment to population ratio by 0.7 p.p. and wages by 1.6%.
- ▶ Roughly 7 jobs per worker.
- ▶ In line with the case-study evidence provided by the International Federation of Robotics.

Quantitative Magnitudes Incorporating Trade

- ▶ Our previous counterfactual misses the aggregate productivity gains:

$$\begin{aligned}\text{Emp. loss} &= \left(\widehat{\beta^L} + \frac{\sigma/\sigma_N}{(1+\varepsilon + \frac{1}{\sigma_N s_{cL}})} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} \\ \text{Wage loss} &= \left(\widehat{\beta^W} + \frac{(\sigma\eta+1)/\sigma_N}{1+\varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i}.\end{aligned}$$

- ▶ We set $\varepsilon = 0.35$, $\sigma_N = 5$, $\sigma = 1$, and $s_{cL} = 0.66$. Also $\eta = 2$.
- ▶ We can then use our regression results:

$$\begin{aligned}\frac{1}{\gamma} &= \beta^W - \beta^L(1+\varepsilon) \\ \mathbb{E} \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] &= \beta^W \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \eta} - \beta^L \frac{\eta(1+\varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \eta}\end{aligned}$$

Quantitative Magnitudes Incorporating Trade

- ▶ Our previous counterfactual misses the aggregate productivity gains:

$$\begin{aligned}\text{Emp. loss} &= \left(\widehat{\beta^L} + \frac{\sigma/\sigma_N}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} \\ \text{Wage loss} &= \left(\widehat{\beta^W} + \frac{(\sigma\eta + 1)/\sigma_N}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i}.\end{aligned}$$

- ▶ We set $\varepsilon = 0.35$, $\sigma_N = 5$, $\sigma = 1$, and $s_{cL} = 0.66$. Also $\eta = 2$.
- ▶ We can then use our regression results:

$$\frac{1}{\gamma} = \beta^W - \beta^L (1 + \varepsilon) = 10.3$$

$$\mathbb{E} \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] = \beta^W \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \eta} - \beta^L \frac{\eta(1 + \varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \eta} = 0.33$$

Quantitative Magnitudes Incorporating Trade

- Our previous counterfactual misses the aggregate productivity gains:

$$\text{Emp. loss} = \left(\widehat{\beta^L} + \frac{\sigma/\sigma_N}{\left(1+\varepsilon+\frac{1}{\sigma_N s_{cL}}\right)} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 0.65 \text{ p.p}$$

$$\text{Wage loss} = \left(\widehat{\beta^W} + \frac{(\sigma\eta+1)/\sigma_N}{1+\varepsilon+\frac{1}{\sigma_N s_{cL}}} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 1.2\%.$$

- We set $\varepsilon = 0.35$, $\sigma_N = 5$, $\sigma = 1$, and $s_{cL} = 0.66$. Also $\eta = 2$.
- We can then use our regression results:

$$\frac{1}{\gamma} = \beta^W - \beta^L (1 + \varepsilon) = 10.3$$

$$\mathbb{E} \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] = \beta^W \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \eta} - \beta^L \frac{\eta(1 + \varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \eta} = 0.33$$

Quantitative Magnitudes Incorporating Trade

- Our previous counterfactual misses the aggregate productivity gains:

$$\text{Emp. loss} = \left(\widehat{\beta^L} + \frac{\sigma/\sigma_N}{(1+\varepsilon + \frac{1}{\sigma_N s_{cL}})} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 0.65\text{p.p}$$

$$\text{Wage loss} = \left(\widehat{\beta^W} + \frac{(\sigma\eta + 1)/\sigma_N}{1 + \varepsilon + \frac{1}{\sigma_N s_{cL}}} \frac{1}{\widehat{\gamma}} \widehat{\mathbb{E}}_c \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] \right) \widehat{\mathbb{E}}_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = 1.2\%$$

- We set $\varepsilon = 0.35$, $\sigma_N = 5$, $\sigma = 1$, and $s_{cL} = 0.66$. Also $\eta = 2$.
- We can then use our regression results:

$$\frac{1}{\gamma} = \beta^W - \beta^L(1 + \varepsilon) = 10.3$$

$$\mathbb{E} \left[1 - \frac{Q_c^* \gamma}{W_c^*} \right] = \beta^W \frac{1 + \eta + \frac{1}{\sigma_N s_{cL}}}{1 + \eta} - \beta^L \frac{\eta(1 + \varepsilon) + \frac{\varepsilon}{\sigma_N s_{cL}}}{1 + \eta} = 0.33$$

- We also estimate that robots raised GDP by $d \ln Y_N = 0.26\%$

1. A model of industrial robots and jobs

2. Empirical specification and data

3. Results

4. Isolating the role of industrial robots

5. Incidence

6. Concluding remarks

Increase in exposure to robots unrelated to pre-existing trends

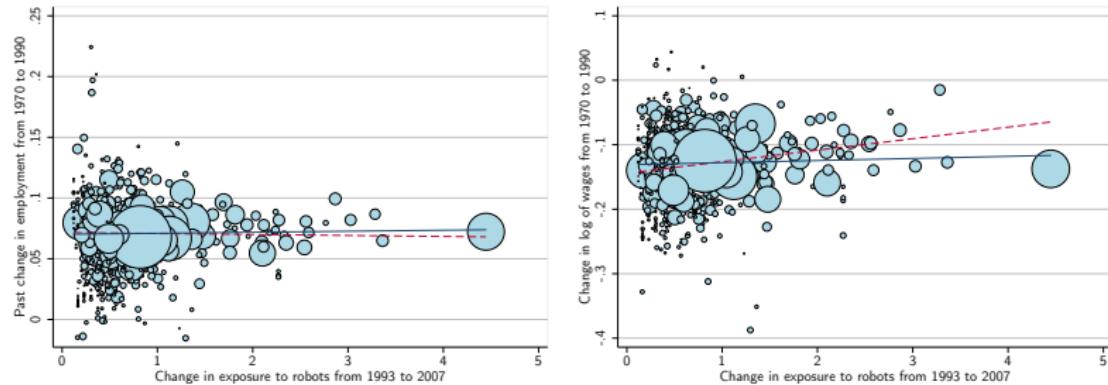


Figure: Regression plots for the impact of the change in exposure to robots from 1993 to 2007 on past changes (from 1970 to 1990) in employment and wages.

Separating the role of industries in decline

Table: Estimates for 1990-2007 that control for the national decline across industries.

	BASELINE		INDUSTRIES IN DECLINE 1970-1990		INDUSTRIES IN DECLINE 1990-2007	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census private employment to population ratio.</i>						
Change in exposure to robots from 1993 to 2007	-0.010*** (0.002)	-0.015*** (0.005)	-0.009*** (0.002)	-0.014*** (0.005)	-0.012*** (0.002)	-0.018*** (0.005)
Bartik measure for industries in decline from 1970 to 1990			-0.116** (0.048)	-0.110** (0.048)		
Bartik measure for industries in decline from 1990 to 2007					-0.139*** (0.039)	-0.138*** (0.038)
Observations	722	714	722	714	722	714
<i>Panel B. log of hourly wages.</i>						
Change in exposure to robots from 1993 to 2007	-0.023*** (0.004)	-0.031*** (0.005)	-0.022*** (0.004)	-0.030*** (0.006)	-0.025*** (0.004)	-0.033*** (0.005)
Bartik measure for industries in decline from 1970 to 1990			-0.097 (0.117)	-0.083 (0.118)		
Bartik measure for industries in decline from 1990 to 2007					-0.155* (0.083)	-0.153* (0.081)
Observations	163114	161042	163114	161042	163114	161042
<i>Covariates & sample restrictions:</i>						
Baseline covariates	✓	✓	✓	✓	✓	✓
Removes highly exposed areas		✓		✓		✓

$$\text{Bartik measure}_c = \sum_{i \in \mathcal{I}} \ell_{ci} \cdot \left(\begin{array}{c} \text{Percent decline in employment} \\ \text{for industry } i \text{ in the US.} \end{array} \right).$$

Robots different from capital deepening in general

Table: Estimates for 1990-2007 of the impact of capital deepening across industries.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Employment to population ratio and capital utilization.</i>						
Capital utilization from 1993 to 2007	0.116 (0.094)	0.061 (0.078)	0.048 (0.069)	0.081 (0.074)	0.021 (0.062)	0.081 (0.074)
Observations	722	722	722	722	721	722
<i>Panel B. log of hourly wages and capital utilization.</i>						
Change in capital utilization from 1993 to 2007	0.424* (0.250)	0.479*** (0.121)	0.399*** (0.141)	0.332** (0.146)	0.080 (0.103)	0.356** (0.148)
Observations	163114	163114	163114	163114	160001	161952
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

$$\text{Capital utilization}_c = \sum_{i \in \mathcal{I}} \ell_{ci} \cdot \left(\begin{array}{l} \text{Percent increase in K/L} \\ \text{for industry } i \text{ in the US.} \end{array} \right).$$

Seems to be unrelated to the computerization of some jobs

Table: Estimates for 1990-2007 of the impact of capital deepening across industries.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Employment to population ratio and capital utilization.</i>						
Change in exposure to robots from 1993 to 2007	-0.013*** (0.004)	-0.011*** (0.003)	-0.010*** (0.002)	-0.010*** (0.002)	-0.010*** (0.003)	-0.015*** (0.005)
Industries with more computerized jobs	-0.006*** (0.000)	-0.002** (0.001)	-0.002 (0.001)	-0.001 (0.002)	-0.003** (0.001)	-0.001 (0.002)
Observations	722	722	722	722	718	714
<i>Panel B. log of hourly wages and capital utilization.</i>						
Change in exposure to robots from 1993 to 2007	-0.038*** (0.006)	-0.026*** (0.004)	-0.023*** (0.004)	-0.022*** (0.004)	-0.029*** (0.004)	-0.031*** (0.006)
Industries with more computerized jobs	-0.002* (0.001)	-0.003* (0.001)	-0.002 (0.001)	-0.001 (0.003)	-0.005** (0.002)	-0.001 (0.003)
Observations	163114	163114	163114	163114	160009	161042
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

$$\text{Computerization}_c = \sum_{i \in \mathcal{I}} \ell_{ci} \cdot \left(\begin{array}{c} \text{Share of computerizable jobs} \\ \text{for industry } i \text{ in the US.} \end{array} \right).$$

The car manufacturing industry does not drive our results

Table: Estimates for 1990-2007 that control for trends in the car-manufacturing industry.

	(1)	(2)	(3)	(4)	(5)
<i>Panel A. Census private employment to population ratio.</i>					
Change in exposure to robots from 1993 to 2007	-0.010*** (0.002)	-0.015*** (0.005)	-0.018*** (0.005)	-0.021*** (0.004)	-0.020*** (0.005)
Change in exposure to robots from 1993 to 2007 in car industry				-0.009*** (0.002)	
Observations	722	714	722	722	722
<i>Panel B. log of hourly wages.</i>					
Change in exposure to robots from 1993 to 2007	-0.023*** (0.004)	-0.031*** (0.005)	-0.024** (0.012)	-0.031*** (0.011)	-0.026** (0.011)
Change in exposure to robots from 1993 to 2007 in car industry				-0.021*** (0.004)	
Observations	163114	161042	163114	163114	162551
<i>Covariates & sample restrictions:</i>					
Baseline covariates	✓	✓	✓	✓	✓
Removes highly exposed areas		✓			
Removes exposure to auto industry			✓	✓	✓
Removes people in auto industry					✓

1. A model of industrial robots and jobs

2. Empirical specification and data

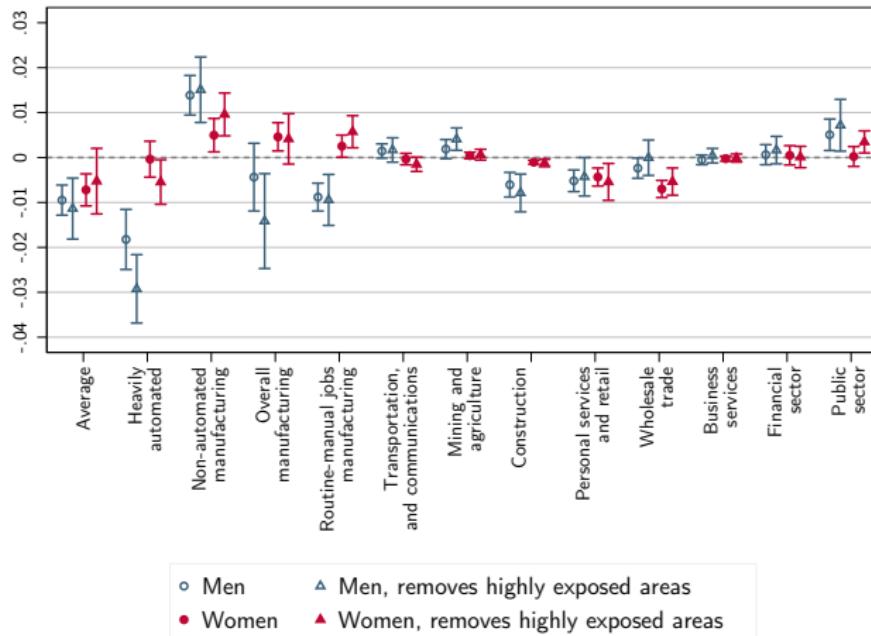
3. Results

4. Isolating the role of industrial robots

5. Incidence

6. Concluding remarks

Effects on different Industries for men and women



- ▶ Heavily robotized: cars, plastic and chemicals, pharmaceuticals, electronics, metal products, and food production.
- ▶ Non-robotized manufacturing: recycling, basic metals, textiles, paper, furniture and transportation equipment (not cars).

Effects on non-robotized industries

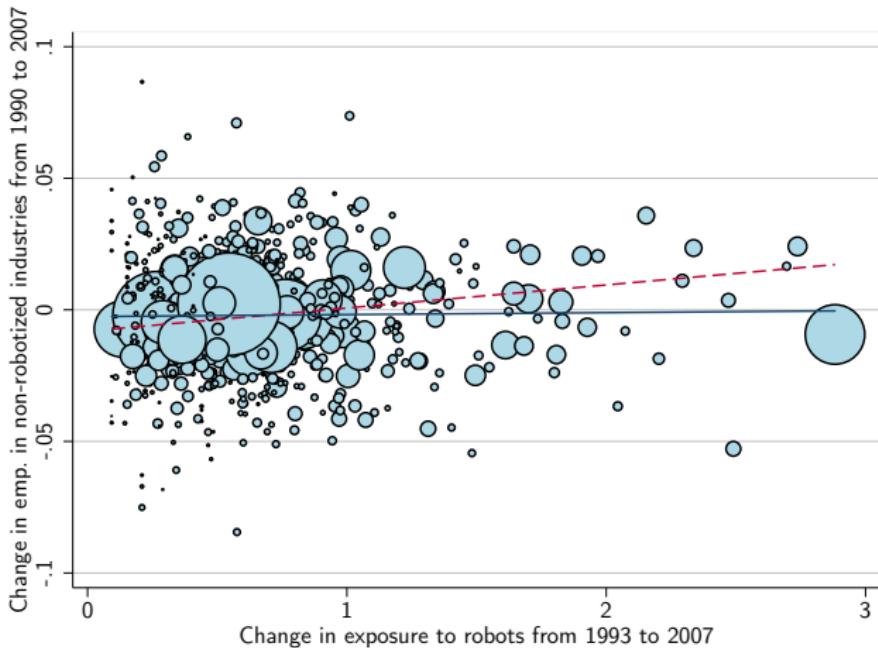
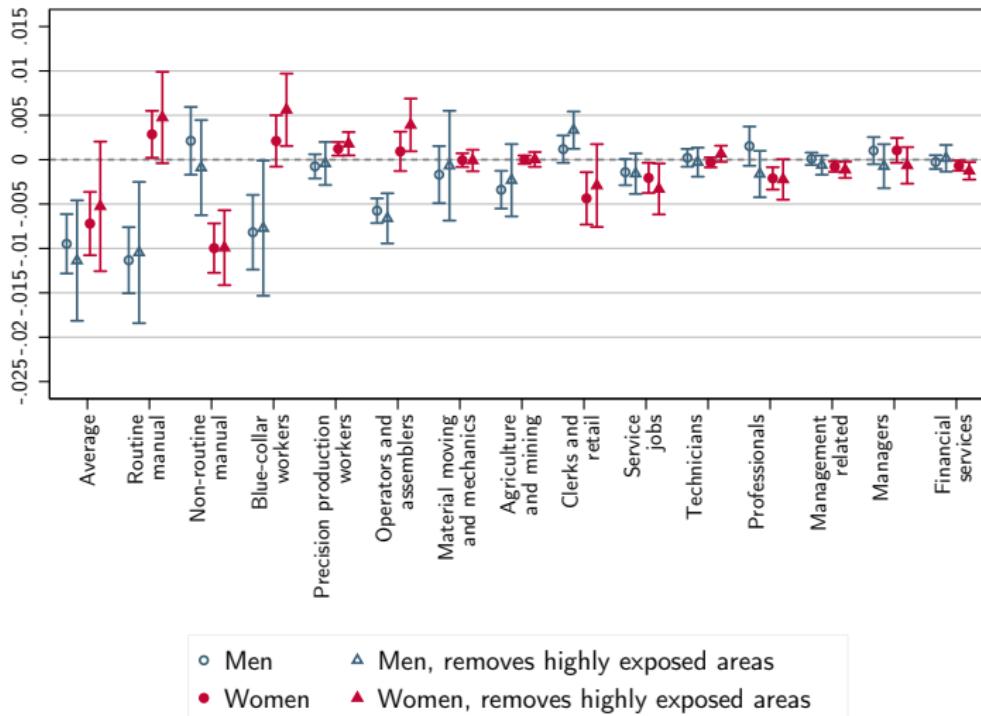
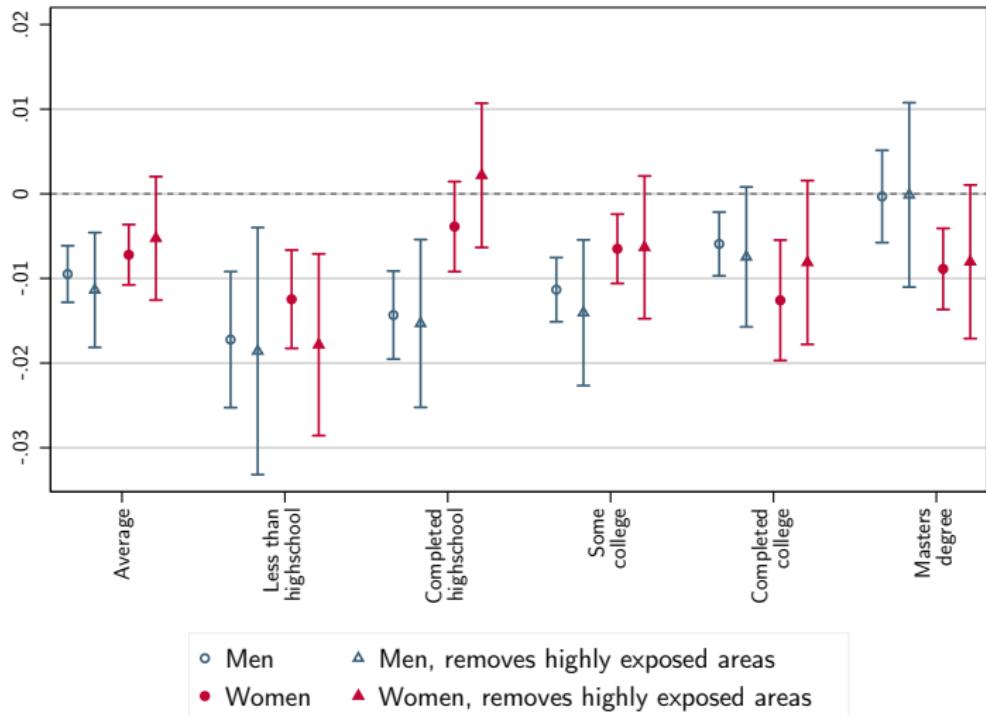


Figure: Regression plots for the impact of the change in exposure to robots from 1993 to 2007 on employment in all non-robotized industries.
Estimate = 0.5 p.p. (standard error = 0.37 p.p.)

Effects on different occupations for men and women



Effects on workers with different skills



1. A model of industrial robots and jobs

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6. Concluding remarks

Work in progress; preliminary conclusions

Some caveats:

- ▶ Our estimates leave out national endogenous technology responses (Acemoglu and Restrepo, 2016).
- ▶ Or other responses that may kick in over time as robots become more important.

But our results so far fairly robust and suggest large negative employment and wage effects from the introduction of robots.

- ▶ Surprising lack of offsetting positive effects in other industries, occupations, or commuting zones. **What is the hold up?**
- ▶ This time is different: unlike previous transformations of the economy, **the demand for labor is not rising fast enough.**
- ▶ Key policy question: **how can we reduce the negative consequences of robots on employment and wages?**

Additional results: full placebo estimates

Table: Placebo test that explores if the exposure to robots is related to past changes in employment from 1970 to 1990.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census private employment to population ratio (1970-1990).</i>						
Change in exposure to robots from 1993 to 2007	-0.001 (0.003)	-0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	-0.005 (0.003)	-0.001 (0.005)
Observations	722	722	722	722	718	714
<i>Panel B. log of hourly wages (1970-1990).</i>						
Change in exposure to robots from 1993 to 2007	-0.014* (0.007)	-0.013* (0.007)	-0.004 (0.008)	0.003 (0.008)	-0.002 (0.007)	0.018 (0.015)
Observations	96487	96487	96487	96487	94804	95109
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	✓
Removes highly exposed areas						✓

Additional results: other employment outcomes

Table: Estimates of the exposure to robots on different measures of employment and unemployment, 1990-2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. log of Census private employment.</i>						
Change in exposure to robots from 1993 to 2007	-0.086*** (0.022)	-0.057*** (0.017)	-0.040*** (0.013)	-0.042*** (0.014)	-0.036*** (0.010)	-0.078*** (0.019)
Observations	722	722	722	722	716	714
<i>Panel B. Employment rate, prime-age.</i>						
Change in exposure to robots from 1993 to 2007	-0.009** (0.004)	-0.009*** (0.002)	-0.008*** (0.002)	-0.008*** (0.002)	-0.008** (0.004)	-0.010** (0.005)
Observations	722	722	722	722	719	714
<i>Panel C. Unemployment rate, prime-age</i>						
Change in exposure to robots from 1993 to 2007	0.004** (0.002)	0.003*** (0.001)	0.002** (0.001)	0.002** (0.001)	0.004*** (0.001)	0.004*** (0.001)
Observations	722	722	722	722	717	714
<i>Panel D. Participation rate, prime-age</i>						
Change in exposure to robots from 1993 to 2007	-0.005 (0.003)	-0.006*** (0.002)	-0.006*** (0.002)	-0.006*** (0.001)	-0.004 (0.003)	-0.007 (0.004)
Observations	722	722	722	722	718	714
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

Additional results: stacked differences

Table: Stacked-difference estimates of the exposure to robots on employment at the commuting zone, 1990-2000 and 2000-2007.

	(1)	(2)	(3)	(4)	(5)
<i>Panel A. Census private employment to population ratio.</i>					
Change in exposure to robots	-0.021*** (0.004)	-0.012*** (0.002)	-0.014*** (0.003)	-0.034*** (0.008)	-0.020*** (0.004)
Observations	1444	1444	1429	1444	1444
<i>Panel B. log of hourly wages.</i>					
Change in exposure to robots	-0.041*** (0.009)	-0.017*** (0.004)	-0.022*** (0.008)	-0.061*** (0.017)	-0.022** (0.009)
Observations	326377	326377	323146	326377	326377
<i>Covariates & sample restrictions:</i>					
Baseline covariates	✓	✓	✓	✓	✓
Covariates × period effects		✓	✓		✓
Removes highly exposed areas			✓		
Commuting zone effects				✓	✓

Additional results: additional covariates or the change in our baseline covariates

Table: Estimates for 1990 to 2007 that control for additional covariates

	LAGGED OUTCOMES		CHANGE IN COVS.		LASSO	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census private employment to population ratio.</i>						
Change in exposure to robots from 1993 to 2007	-0.007*** (0.002)	-0.008* (0.004)	-0.009*** (0.002)	-0.013*** (0.004)	-0.012*** (0.003)	-0.018*** (0.004)
Observations	722	714	722	714	722	714
<i>Panel B. log of hourly wages.</i>						
Change in exposure to robots from 1993 to 2007	-0.023*** (0.004)	-0.029*** (0.005)	-0.025*** (0.004)	-0.028*** (0.006)	-0.026*** (0.006)	-0.025** (0.011)
Observations	134404	132624	163114	161042	163114	161042
<i>Covariates & sample restrictions:</i>						
Baseline covariates	✓	✓	✓	✓	✓	✓
Removes highly exposed areas		✓		✓		✓
Lagged outcomes	✓	✓		✓		✓
Change of covariates				✓		
LASSO selected covariates					✓	✓

Additional results: effects by gender

Table: Estimates of the exposure to robots on the labor market outcomes of men and women, 1990-2007.

	ESTIMATES FOR MEN			ESTIMATES FOR WOMEN		
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census private employment to population ratios.</i>						
Change in exposure to robots from 1993 to 2007	-0.013*** (0.002)	-0.013*** (0.002)	-0.021*** (0.006)	-0.007*** (0.002)	-0.008*** (0.002)	-0.010** (0.005)
Observations	722	722	714	722	722	714
<i>Panel B. log of Census private employment counts.</i>						
Change in exposure to robots from 1993 to 2007	-0.044*** (0.015)	-0.045*** (0.016)	-0.088*** (0.022)	-0.035*** (0.013)	-0.038*** (0.013)	-0.066*** (0.018)
Observations	722	722	714	722	722	714
<i>Panel C. log of hourly wages.</i>						
Change in exposure to robots from 1993 to 2007	-0.024*** (0.005)	-0.022*** (0.005)	-0.037*** (0.006)	-0.024*** (0.004)	-0.024*** (0.004)	-0.025*** (0.007)
Observations	80930	80930	79897	82184	82184	81145
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics and industry shares	✓	✓	✓	✓	✓	✓
Trade and routinization		✓	✓		✓	✓
Removes highly exposed areas			✓			✓

Additional results: net migration

Table: Estimates of the exposure to robots on population and net migration, 1990-2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. log of population.</i>						
Change in exposure to robots from 1993 to 2007	-0.050*** (0.014)	-0.024 (0.014)	-0.015 (0.013)	-0.016 (0.014)	-0.011 (0.012)	-0.037 (0.022)
Observations	722	722	722	722	715	714
<i>Panel B. log of male population.</i>						
Change in exposure to robots from 1993 to 2007	-0.048*** (0.015)	-0.019 (0.015)	-0.011 (0.014)	-0.013 (0.015)	-0.007 (0.012)	-0.034 (0.023)
Observations	722	722	722	722	714	714
<i>Panel C. log of female population.</i>						
Change in exposure to robots from 1993 to 2007	-0.052*** (0.014)	-0.028** (0.014)	-0.019 (0.013)	-0.020 (0.014)	-0.016 (0.012)	-0.039* (0.021)
Observations	722	722	722	722	715	714
<i>Panel D. Net migration rate.</i>						
Change in exposure to robots from 1993 to 2007	-0.0017 (0.0010)	-0.0017*** (0.0006)	-0.0014** (0.0006)	-0.0015** (0.0006)	-0.0004 (0.0006)	-0.0007 (0.0012)
Observations	722	722	722	722	691	714
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

Additional results: total income and non-labor income

Table: Estimates of the change in exposure to robots on income per capita, 1990-2007.

	ESTIMATES FOR INCOME AND TRANSFERS FROM 1990 TO 2007			
	CHANGE IN LEVELS		CHANGE IN LOGS	
	(1)	(2)	(3)	(4)
<i>Panel A. Total income from the IRS</i>				
Change in exposure to robots from 1993 to 2007	85.154 (284.637)	-170.963 (413.671)	-0.021*** (0.007)	-0.028** (0.012)
Observations	722	714	722	714
<i>Panel B. Total non-wage income from the IRS</i>				
Change in exposure to robots from 1993 to 2007	190.476 (118.649)	20.637 (185.896)	0.008 (0.013)	0.015 (0.022)
Observations	722	714	722	714
<i>Panel C. Total income from the BEA</i>				
Change in exposure to robots from 1993 to 2007	-985.376* (563.588)	-1686.296** (812.698)	-0.040*** (0.010)	-0.049*** (0.015)
Observations	722	714	722	714
<i>Panel C. Total non-wage income from the BEA</i>				
Change in exposure to robots from 1993 to 2007	250.025 (404.350)	441.995 (711.930)	-0.001 (0.020)	0.008 (0.037)
Observations	722	714	721	713
<i>Covariates & sample restrictions:</i>				
Baseline covariates	✓	✓	✓	✓
Removes highly exposed areas		✓		✓

Additional results: full period from 1990-2014

Table: Estimates of the exposure to robots for 1990 to 2014.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Census employment to population ratio.</i>						
Change in exposure to robots from 1993 to 2014	-0.016*** (0.005)	-0.009*** (0.003)	-0.006** (0.003)	-0.006** (0.003)	-0.008*** (0.002)	-0.011** (0.005)
Observations	722	722	722	722	719	714
<i>Panel B. log of hourly wages.</i>						
Change in exposure to robots from 1993 to 2014	-0.035*** (0.004)	-0.030*** (0.004)	-0.028*** (0.004)	-0.026*** (0.004)	-0.028*** (0.004)	-0.033*** (0.006)
Observations	144101	144101	144101	144101	142451	142337
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	✓
Removes highly exposed areas						✓

Additional results: Great Recession

Table: Estimates during the Great Recession

	(1)	(2)	(3)	(4)	(5)	(6)
ESTIMATES FROM 2007 TO 2011						
<i>Panel A. Census private employment to population ratio</i>						
Change in exposure to robots from 2007 to 2014	-0.010** (0.004)	-0.007*** (0.002)	-0.006*** (0.002)	-0.006** (0.002)	-0.007** (0.003)	-0.008 (0.006)
Observations	722	722	722	722	722	714
<i>Panel B. log of hourly wages</i>						
Change in exposure to robots from 2007 to 2014	-0.032*** (0.004)	-0.032*** (0.005)	-0.033*** (0.005)	-0.032*** (0.005)	-0.025*** (0.006)	-0.048*** (0.011)
Observations	127542	127542	127542	127542	143402	125933
ESTIMATES FROM 2007 TO 2014						
<i>Panel C. Census private employment to population ratio</i>						
Change in exposure to robots from 2007 to 2014	-0.004 (0.005)	0.001 (0.003)	0.003 (0.003)	0.003 (0.003)	0.003 (0.004)	0.001 (0.007)
Observations	722	722	722	722	720	714
<i>Panel D. log of hourly wages</i>						
Change in exposure to robots from 2007 to 2014	-0.031*** (0.006)	-0.032*** (0.005)	-0.031*** (0.004)	-0.030*** (0.005)	-0.022*** (0.006)	-0.028** (0.013)
Observations	133192	133192	133192	133192	153913	131513
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	
Removes highly exposed areas						✓

Additional results: IV estimates for 2004-2007

Table: IV estimates of the exposure to robots on CBP employment counts, 2004-2007.

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. CBP employment to population ratio, OLS.</i>						
Change in exposure to robots from 2004 to 2007 in U.S. industries	-0.019*** (0.003)	-0.019*** (0.003)	-0.018*** (0.003)	-0.017*** (0.003)	-0.009*** (0.003)	-0.014** (0.006)
Observations	722	722	722	722	711	714
<i>Panel B. CBP employment to population ratio, reduced-form.</i>						
Change in exposure to robots from 2004 to 2007	-0.027*** (0.004)	-0.027*** (0.005)	-0.026*** (0.005)	-0.025*** (0.005)	-0.008* (0.004)	-0.021** (0.008)
Observations	722	722	722	722	711	714
<i>Panel C. IV estimates for the CBP employment to population ratio, IV.</i>						
Instrumented change in exposure to robots from 2004 to 2007	-0.021*** (0.002)	-0.020*** (0.003)	-0.019*** (0.003)	-0.018*** (0.003)	-0.008** (0.003)	-0.017** (0.007)
Observations	722	722	722	722	711	714
First-stage F statistic	160.1	589.3	518.4	559.3	257.0	151.3
<i>Covariates & sample restrictions:</i>						
Census division dummies	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓
Trade and routinization				✓	✓	✓
Down-weights outliers					✓	✓
Removes highly exposed areas						✓