Robots and Jobs: Evidence from US Labor Markets

Daron Acemoglu and Pascual Restrepo

James J. Heckman

THE UNIVERSITY OF CHICAGO

Econ 350, Winter 2023

1. Introduction

2. Robots, Employment and Wages: A Model

2.1 Robots in Autarky Equilibrium

The economy consists of $|\mathcal{C}|$ commuting zones. Each commuting zone $c \in \mathcal{C}$ has preferences defined over an aggregate of the consumption of the output of $|\mathcal{I}|$ industries, given by

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

where $\sigma > 0$ denotes the elasticity of substitution across goods produced in different industries, while the α_i's are share parameters designating the importance of industry i in the consumption aggregate (with $\sum_{i \in \mathcal{I}} \alpha_i = 1$).

In the autarky equilibrium, each commuting zone can consume only its own production of each good, denoted by X_{ci} for the output of industry i in commuting zone c. Hence, for all $i \in \mathcal{I}$ and $c \in \mathcal{C}$, we have

$$Y_{ci} = X_{ci}.$$

Each industry produces output by combining a continuum of tasks indexed by $s \in [0, S]$. We denote by $x_{ci}(s)$ the quantity of task s utilized in the production of X_{ci}. These tasks must be combined in fixed proportions so that

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

where A_{ci} designates the productivity of industry i. Differences in the A_{ci}'s and the α_i's will translate into different industrial compositions of employment across commuting zones.

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

Finally, we specify the supply of robots and labor in each commuting zone as follows

$$
\begin{aligned}
W_c &= \mathcal{W}_c Y_c L_c^\varepsilon, \text{ with } \varepsilon \geq 0; \text{ and} \\
Q_c &= \mathcal{Q}_c \left(\frac{R_c}{Y_c} \right)^\eta, \text{ with } \eta \geq 0,
\end{aligned}
\tag{2}
$$

An equilibrium is defined as a set of prices $\{W_c, Q_c\}_{c \in \mathcal{C}}$ and quantities $\{L_c, R_c\}_{c \in \mathcal{C}}$ such that in all commuting zones, firms maximize profits, labor and robot supplies are given by (2) and the markets for labor and robots clear, i.e.,

$$\sum_{i \in \mathcal{I}} \int_{[0,1]} l_{ci}(s) = L_c \qquad \text{and} \qquad \sum_{i \in \mathcal{I}} \int_{[0,1]} r_{ci}(s) = R_c. \qquad (3)$$

ASSUMPTION 1 $\pi_c > 0$ for all $c \in \mathcal{C}$.

This assumption allows us to focus on the case of interest in which improvements in automation (increases in M_i) are binding and affect wages and employment. Using this assumption, we can derive an expression for the demand for labor L_c^d.

PROPOSITION 1 *The demand for labor L_c^d in commuting zone c satisfies:*

$$d \ln L_c^d = -\sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} - \sigma \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Xci} + d \ln Y_c, \tag{4}$$

PROPOSITION 2 *In autarky, the impact of robots on employment and wages is given by*

$$d \ln L_c = -\frac{1+\eta}{1+\varepsilon} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1-M_i} + \frac{1+\eta}{1+\varepsilon} \pi_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{s_{icL}}{s_{cL}} \frac{dM_i}{1-M_i} \tag{5}$$

$$d \ln W_c = -\eta \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1-M_i} + (1+\eta) \pi_c \sum_{i \in \mathcal{I}} \ell_{ci} \frac{s_{icL}}{s_{cL}} \frac{dM_i}{1-M_i}. \tag{6}$$

Proposition 2 summarizes the effects of robots as a function of the changes in the robotics technology, dM_i. More convenient for our empirical work is to link the responses of employment and wages to changes in the adoption of robots. When $M_i \approx 0$—a reasonable approximation to the US economy circa 1990—this can be done in the following fashion:[8]

$$\sum_{i \in \mathcal{I}} \ell_{ci} \frac{s_{icL}}{s_{cL}} \frac{dM_i}{1 - M_i} \approx \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} \approx \frac{1}{\gamma} \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} = \textit{US exposure to robots} \qquad (7)$$

2.2 Robots When Commuting Zones Trade

Preferences in each commuting zone are again defined by the same aggregate over consumption goods as in (1), but now these consumption goods are themselves assumed to be aggregates of varieties sourced from all commuting zones, given by

$$Y_{ci} = \left(\sum_{s \in \mathcal{C}} \theta_{si} X_{sci}^{\frac{\lambda-1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}} \quad \text{(for all } c \text{ and } i\text{),} \tag{8}$$

An equilibrium is defined in the same way as in the closed economy, but now requires, in addition, that trade is balanced for each commuting zone $c \in \mathcal{C}$, i.e.,

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

PROPOSITION 3 *In the trading equilibrium, the demand for labor L_c^d in commuting zone c satisfies:*

$$d \ln L_c^d = -\sum_{i \in \mathcal{I}} \ell_{ci} \frac{dM_i}{1 - M_i} - \lambda \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Xci} + (\lambda - \sigma) \sum_{i \in \mathcal{I}} \ell_{ci} d \ln P_{Yi} + d \ln Y. \qquad (9)$$

3. Empirical Specification

We now discuss the implications of the autarky and the trading equilibria for our empirical strategy.

When $M_i \approx 0$, both our autarky and trade models imply that the effects of robots on employment and wages can be estimated using the following two equations:

$$d \ln L_c = \beta_c^L \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} + \epsilon_c^L \qquad \text{and} \qquad d \ln W_c = \beta_c^W \sum_{i \in \mathcal{I}} \ell_{ci} \frac{dR_i}{L_i} + \epsilon_c^W, \qquad (10)$$

where ϵ_c^L and ϵ_c^W are unobserved shocks, and β_c^L and β_c^W are random (heterogeneous) coefficients. In the autarky equilibrium, equation (7) implies that these coefficients are given as

$$\beta_c^L = \left(\frac{1+\eta}{1+\varepsilon} \pi_c - \frac{1+\eta}{1+\varepsilon} \right) \frac{1}{\gamma} \qquad \text{and} \qquad \beta_c^W = ((1+\eta)\pi_c - \eta) \frac{1}{\gamma}.$$

In this autarky setting, aggregate effects of robots are also given by averages of these heterogeneous coefficients.

More realistic and relevant for our investigation is the setting with trade between commuting zones. In this case, when in addition $\pi_c \approx \pi$, the expressions in Proposition A3 can be simplified to yield the following approximations to β_c^L and β_c^W:

$$\beta_c^L \approx \left(\frac{1+\eta}{1+\varepsilon}(s_{cL}\lambda + (1-s_{cL})\sigma)\pi_c - \frac{1+\eta}{1+\varepsilon}\frac{s_{cL}\lambda + 1 - s_{cL}}{s_{cL}} \right) \frac{\nu_c}{\gamma} \tag{11}$$

$$\beta_c^W \approx \left(\left((1+\eta)\frac{(1+\varepsilon)\lambda - 1}{1+\varepsilon} - (1+\eta(1-s_{cL}))(\lambda - \sigma) \right) \pi_c - \left(\eta(\lambda - 1) + \frac{\varepsilon(1+\eta)}{(1+\varepsilon)s_{cL}} \right) \right) \frac{\nu_c}{\gamma},$$

where

$$\nu_c = \frac{(1+\varepsilon)s_{cL}}{(1+\varepsilon)s_{cL}\lambda + (1+\eta)(1-s_{cL})}.$$

In fact, again focusing on the case where $\pi_c \approx \pi$, the Appendix shows that the aggregate employment and wage effects are

$$\text{aggregate employment effects} \quad = \quad \frac{1+\eta}{1+\varepsilon}(\pi-1)\frac{1}{\gamma}\mathbb{E}_c\sum_{i\in\mathcal{I}}\ell_{ci}\frac{dR_i}{L_i} \qquad (12)$$

$$\text{aggregate wage effects} \quad = \quad ((1+\eta)\pi-\eta)\frac{1}{\gamma}\mathbb{E}_c\sum_{i\in\mathcal{I}}\ell_{ci}\frac{dR_i}{L_i},$$

4. Data, Descriptive Statistics and First Stage

4.1 Data Sources

4.2 Exposure to Robots

These observations motivate the construction of our exposure to robots variable as

$$\text{\textit{Exposure to robots from 1993 to 2007}}_c = \sum_{i\in\mathcal{I}} \ell_{ci}^{1970}\left(p_{30}\left(\frac{R_{i,2007}}{L_{i,1990}}\right) - p_{30}\left(\frac{R_{i,1993}}{L_{i,1990}}\right)\right),\tag{13}$$

We construct the US exposure to robots in an analogous fashion:

$$\text{US exposure to robots from 2004 to 2007}_c = \sum_{i \in \mathcal{I}} \ell_{ci}^{1990} \left(\frac{R_{i,2007}^{US}}{L_{i,1990}^{US}} - \frac{R_{i,2004}^{US}}{L_{i,1990}^{US}} \right), \tag{14}$$

where we use the 1990 distribution of employment across industries, ℓ_{ci}^{1990}, as the baseline for this measure to match it more closely to theory (and the mean reversion concern mentioned above is not pertinent in this case, since this measure will be instrumented by the exogenous

4.3 Descriptive Statistics

4.4 First Stage

Figure 5 provides a visual representation of our first-stage relationship in the form of a residual plot. The first stage, which will be used in our instrumental variables exercises and is shown in this figure, links the US exposure to robots to the (exogenous) exposure to robots computed from the European data. More precisely, our first stage takes the form

$$\sum_{i \in \mathcal{I}} \ell_{ci}^{1990} \left(\frac{R_{i,2007}^{US}}{L_{i,1990}^{US}} - \frac{R_{i,2004}^{US}}{L_{i,1990}^{US}} \right) = \pi \sum_{i \in \mathcal{I}} \ell_{ci}^{1970} \left(p_{30} \left(\frac{R_{i,2007}}{L_{i,1990}} \right) - p_{30} \left(\frac{R_{i,1993}}{L_{i,1990}} \right) \right) + \Gamma X_{c,1990} + \nu_c,$$

(15)

where $X_{c,1990}$ is a vector of controls, and as noted above, p_{30} denotes the 30th percentile.

5. Results

5.1 Baseline Results for Employment

5.2 Baseline Results for Wages

We next turn to the impact of robots on wages. Because robots affect employment, they are also likely to influence the composition of employed workers. To minimize the impact of such compositional changes, we estimate a variant of equation (10) that fully takes into account the differences in the observable characteristics of employed individuals. In particular, our estimating equation is now

$$\ln W_{cg,2007} - \ln W_{cg,1990} = \beta^W \cdot \textit{Exposure to robots 1993-2007}_c + \epsilon_{cg}^W,$$

5.3 Two-Stage Least Squares Estimates

5.4 Quantitative Magnitudes

5.5 Placebo Checks

5.6 Robustness Checks

5.7 Isolating the Impact of Robots
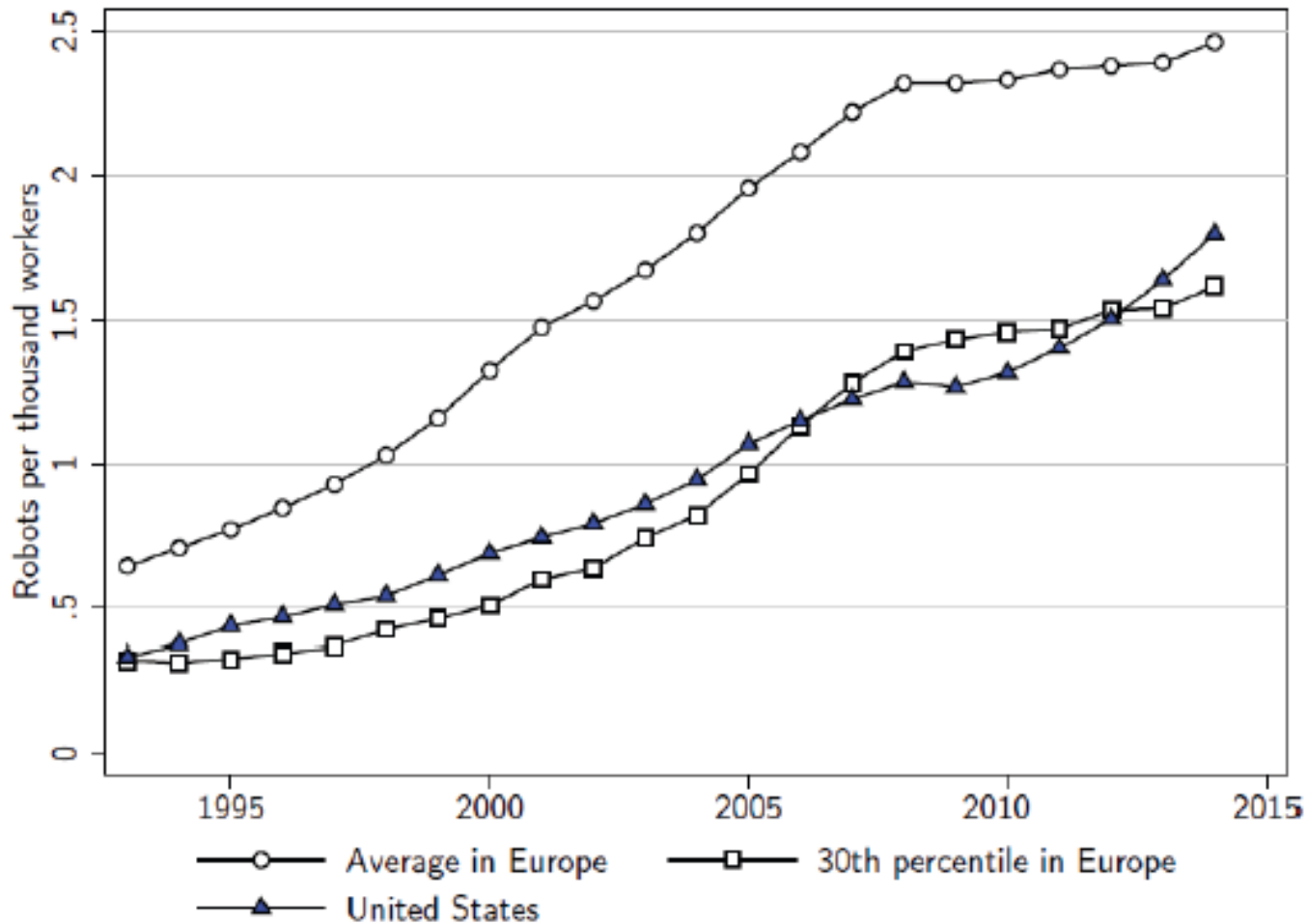
5.8 Effects on Men and Women

5.9 Effects by Industry, Occupation, Education and Wage Percentile

5.10 Total and Non-Labor Income
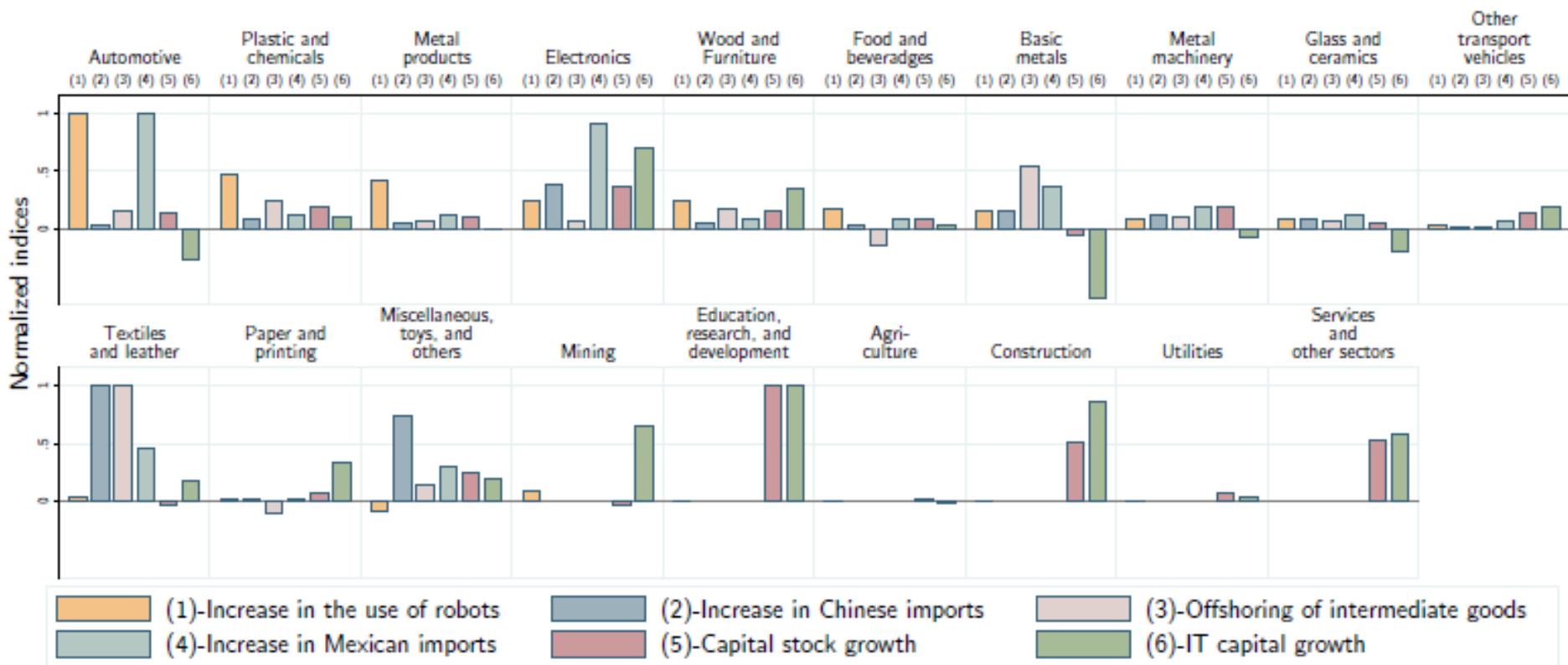
5.11 Back to Quantitative Magnitudes

6. Concluding Remarks

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).
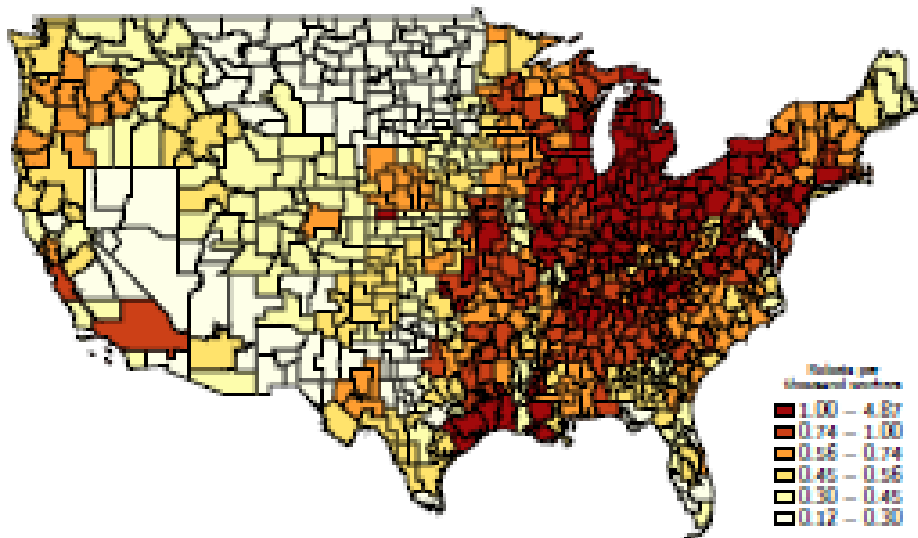
Figure 2: Industry-level changes in the use of robots, Chinese imports, capital stock and IT capital
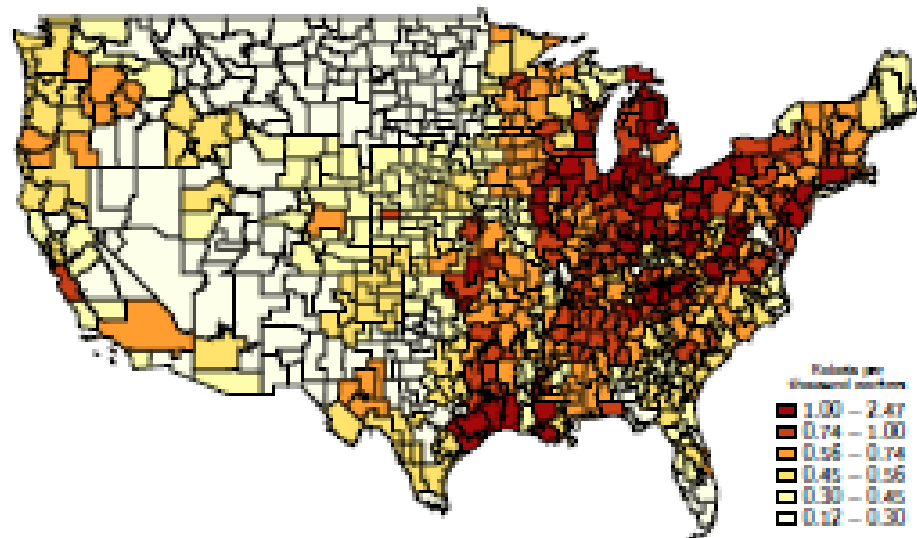

Note: This figure plots the increase in the number of robots per thousand workers between 1993 and 2007, the increase in the dollar value of Chinese imports per worker between 1990 and 2007, the growth of the capital stock between 1990 and 2007, and the growth of the stock of IT capital between 1990 and 2007 for the 19 industries for which we have the IFR data.

Figure 3: Geographic distribution of the exposure to robots, the exposure to Chinese imports, Mexican imports, routine jobs, and the exposure to offshoring

Note: The maps depict the distribution of our exposure to robots variable (both with and without the exposure resulting from automotive manufacturing), the exposure to Chinese imports from 1990 to 2007 (from Autor, Dorn and Hanson, 2013), the exposure to Mexican imports from 1991 to 2007, the share of employment in routine jobs (as defined in Autor, Dorn, and Hanson, 2015), and the exposure to the offshoring of intermediate inputs from 1993 to 2007 (from Feenstra and Hanson, 1999, and extended by Wright, 2014). The population-weighted correlation between exposure to robots and the exposure to Chinese imports is 0.049 (and -0.0518 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between the exposure to robots and exposure to Mexican imports is 0.43 (and 0.26 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the share of routine jobs is 0.28 (and 0.11 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the exposure to offshoring is 0.054 (and -0.002 conditional on the covariates included in column 3 of Table 2).

C. Exposure to Chinese imports from 1990 to 2007

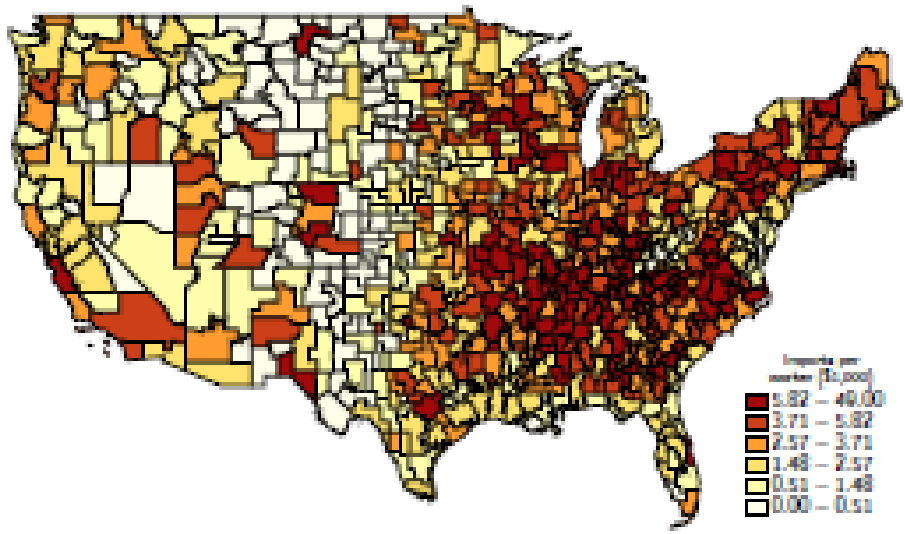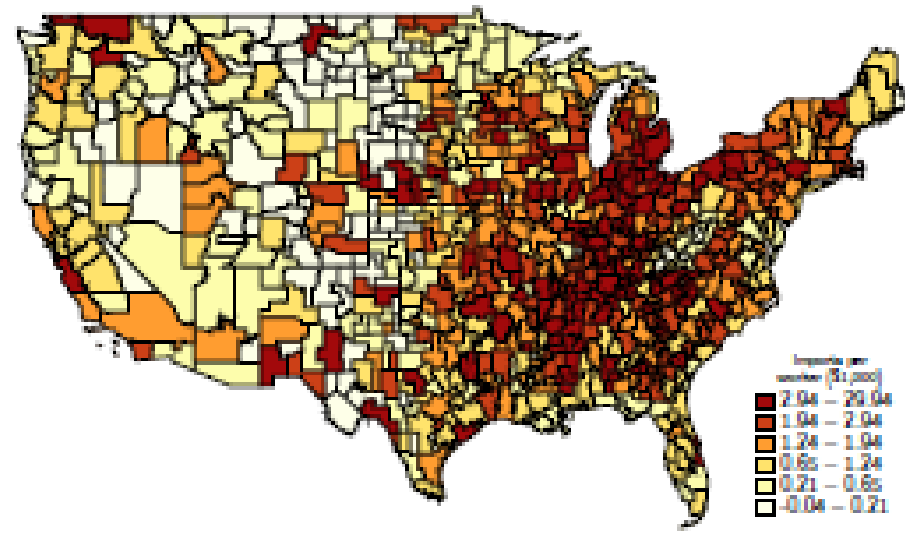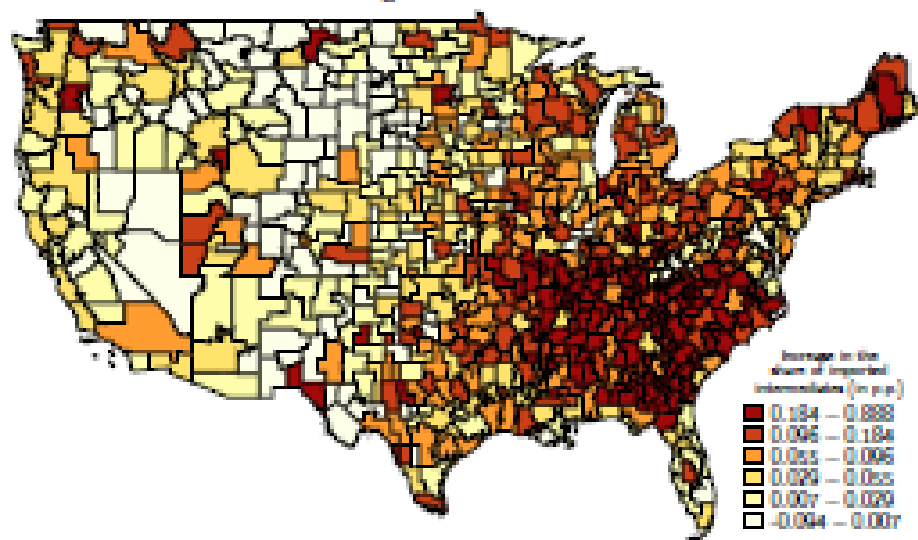F. Exposure to Mexican imports from 1993 to 2007

Note: The maps depict the distribution of our exposure to robots variable (both with and without the exposure resulting from automotive manufacturing), the exposure to Chinese imports from 1990 to 2007 (from Autor, Dorn and Hanson, 2013), the exposure to Mexican imports from 1991 to 2007, the share of employment in routine jobs (as defined in Autor, Dorn, and Hanson, 2015), and the exposure to the offshoring of intermediate inputs from 1993 to 2007 (from Feenstra and Hanson, 1999, and extended by Wright, 2014). The population-weighted correlation between exposure to robots and the exposure to Chinese imports is 0.049 (and -0.0518 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between the exposure to robots and exposure to Mexican imports is 0.43 (and 0.26 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the share of routine jobs is 0.28 (and 0.11 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the exposure to offshoring is 0.054 (and -0.002 conditional on the covariates included in column 3 of Table 2).

Figure 3: Geographic distribution of the exposure to robots, the exposure to Chinese imports, Mexican imports, routine jobs, and the exposure to offshoring, Cont'd
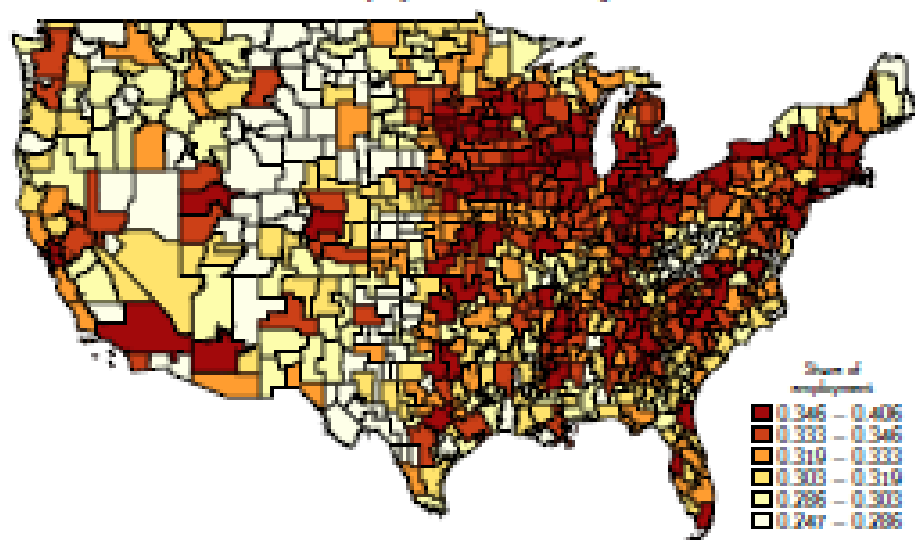
Note: The maps depict the distribution of our exposure to robots variable (both with and without the exposure resulting from automotive manufacturing), the exposure to Chinese imports from 1990 to 2007 (from Autor, Dorn and Hanson, 2013), the exposure to Mexican imports from 1991 to 2007, the share of employment in routine jobs (as defined in Autor, Dorn, and Hanson, 2015), and the exposure to the offshoring of intermediate inputs from 1993 to 2007 (from Feenstra and Hanson, 1999, and extended by Wright, 2014). The population-weighted correlation between exposure to robots and the exposure to Chinese imports is 0.049 (and -0.0518 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between the exposure to robots and exposure to Mexican imports is 0.43 (and 0.26 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the share of routine jobs is 0.28 (and 0.11 conditional on the covariates included in column 3 of Table 2). The population-weighted correlation between exposure to robots and the exposure to offshoring is 0.054 (and -0.002 conditional on the covariates included in column 3 of Table 2).

Figure 4: The relationship between robots adoption in Europe and the United States
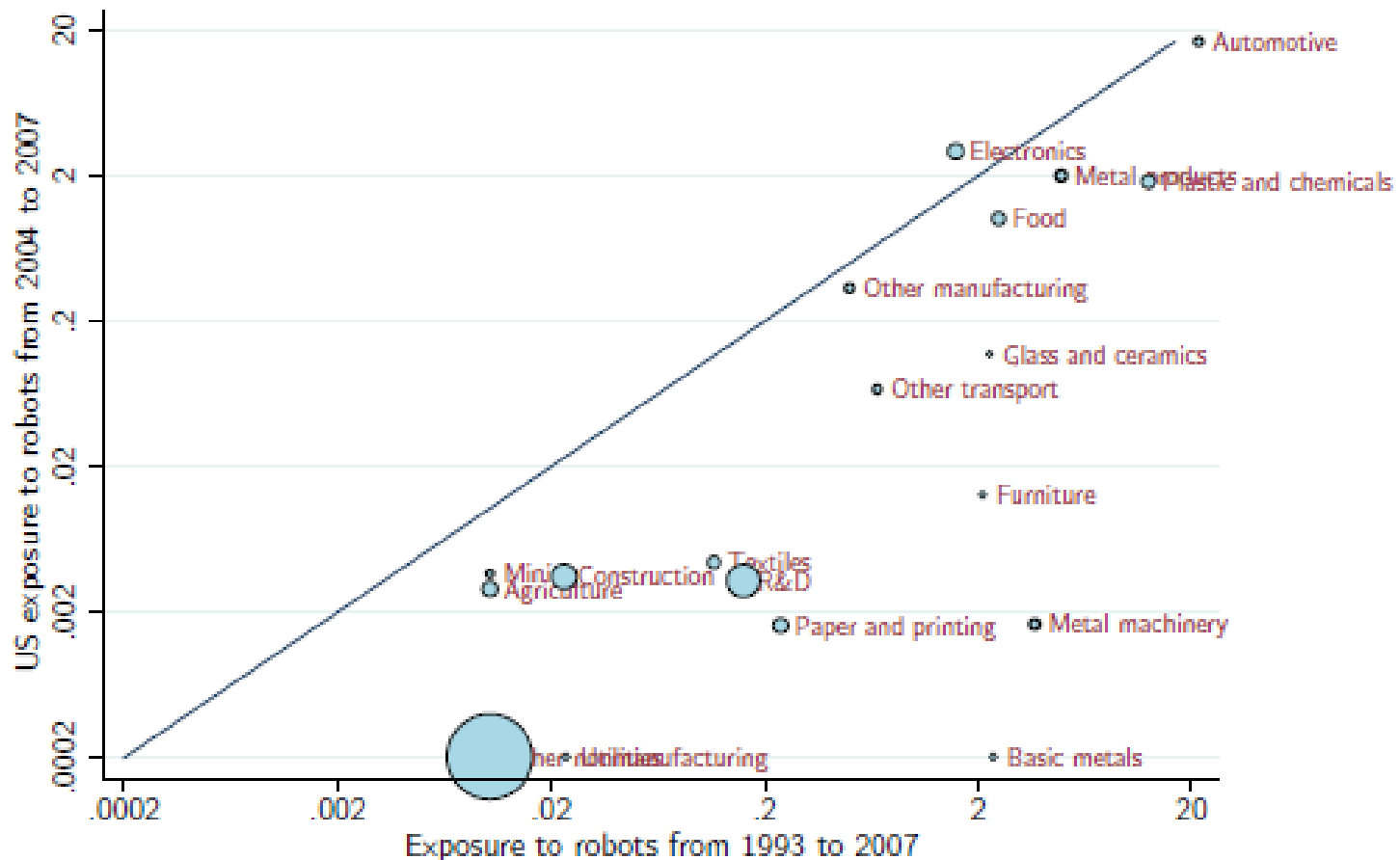
Note: The top panel gives the scatter plot of the change in the number of robots per thousand workers in Europe between 1993 and 2007 and in the United States between 2004 and 2007. The bottom panel shows the same relationship using the change in the number of robots per thousand workers in Europe between 2004 and 2007. The solid line corresponds to the 45o line. Marker size indicates the share of US employment in the corresponding industry.

Figure 4: The relationship between robots adoption in Europe and the United States, Cont'd

Note: The top panel gives the scatter plot of the change in the number of robots per thousand workers in Europe between 1993 and 2007 and in the United States between 2004 and 2007. The bottom panel shows the same relationship using the change in the number of robots per thousand workers in Europe between 2004 and 2007. The solid line corresponds to the 45o line. Marker size indicates the share of US employment in the corresponding industry.

Note: The figure shows the residual plot of US exposure to robots between 2004 and 2007 (converted to a 17-year equivalent change) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. The solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights (coefficient =2.026, standard error = 0.275). The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded (coefficient =1.083, standard error = 0.135). Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

Figure 6: Relationship between the exposure to robots and the number of robot integrators
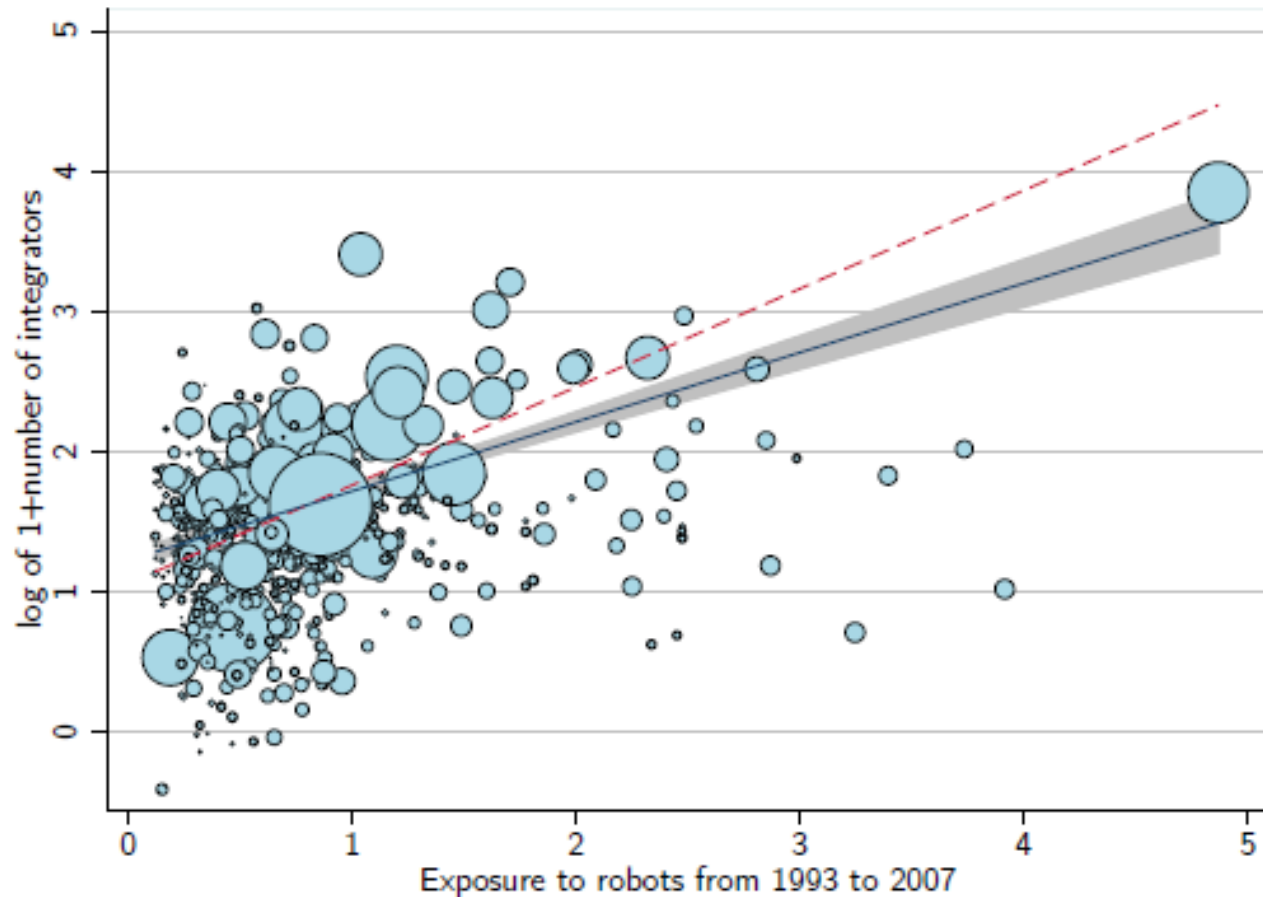
Note: The figure shows the residual plot of the log of one plus the number of integrators in a commuting zone against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. The data on the location of robot integrators—the companies that program and adapt robots for a given industrial application— is from Green Leigh and Kraft (2016). The solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights (coefficient =0.501, standard error = 0.072). The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded (coefficient =0.681, standard error = 0.142). Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

Figure 7: Relationship between the exposure to robots and employment

Note: The figure shows the residual plot of the change in the employment to population ratio (Census private employment in the top panel; CBP employment in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

Figure 7: Relationship between the exposure to robots and employment, Cont'd

Note: The figure shows the residual plot of the change in the employment to population ratio (Census private employment in the top panel; CBP employment in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

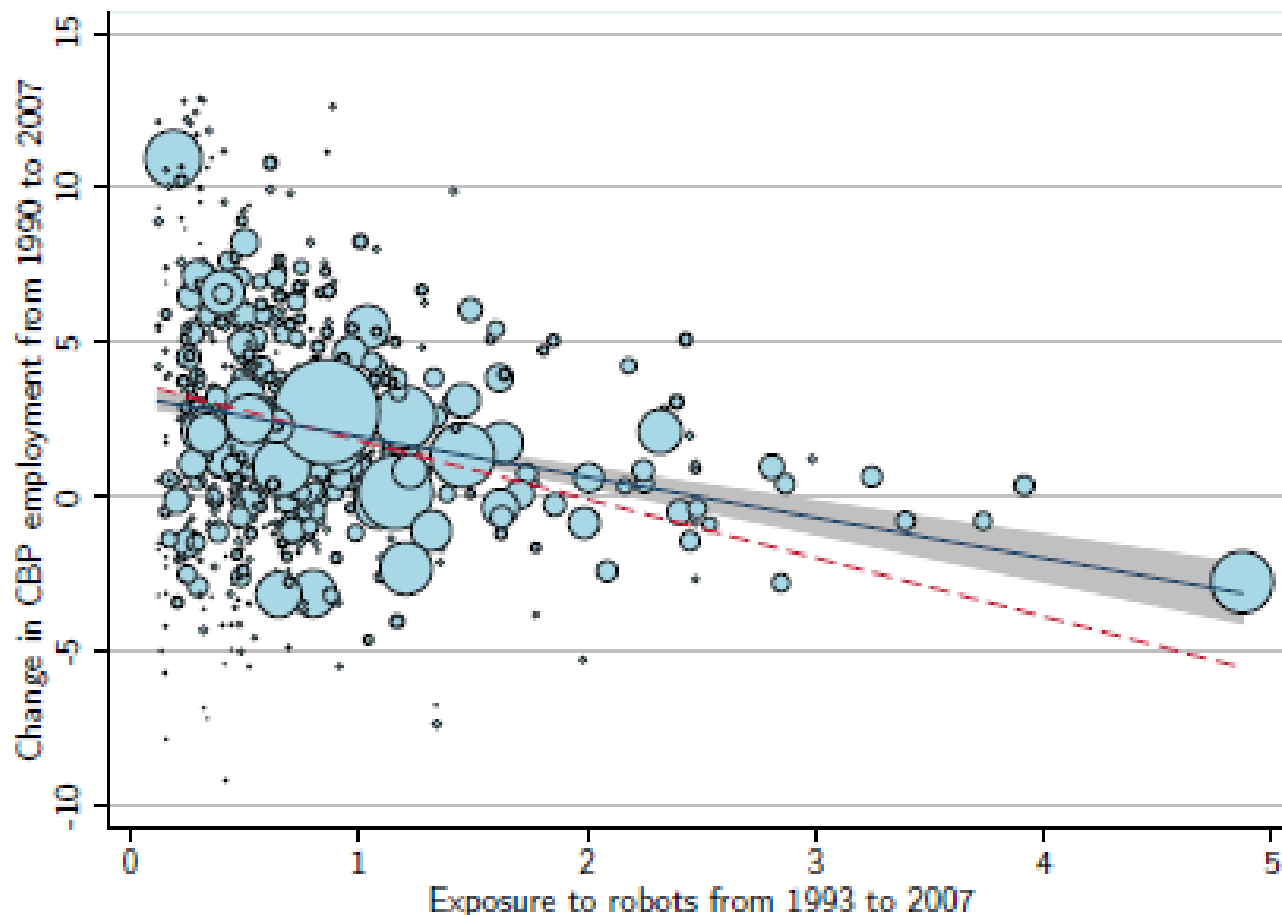# Figure 8: Relationship between the exposure to robots and wages

Note: The figure shows the residual plot of the change in the log of wages (hourly wages in the top panel; weekly wages in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The red dot line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

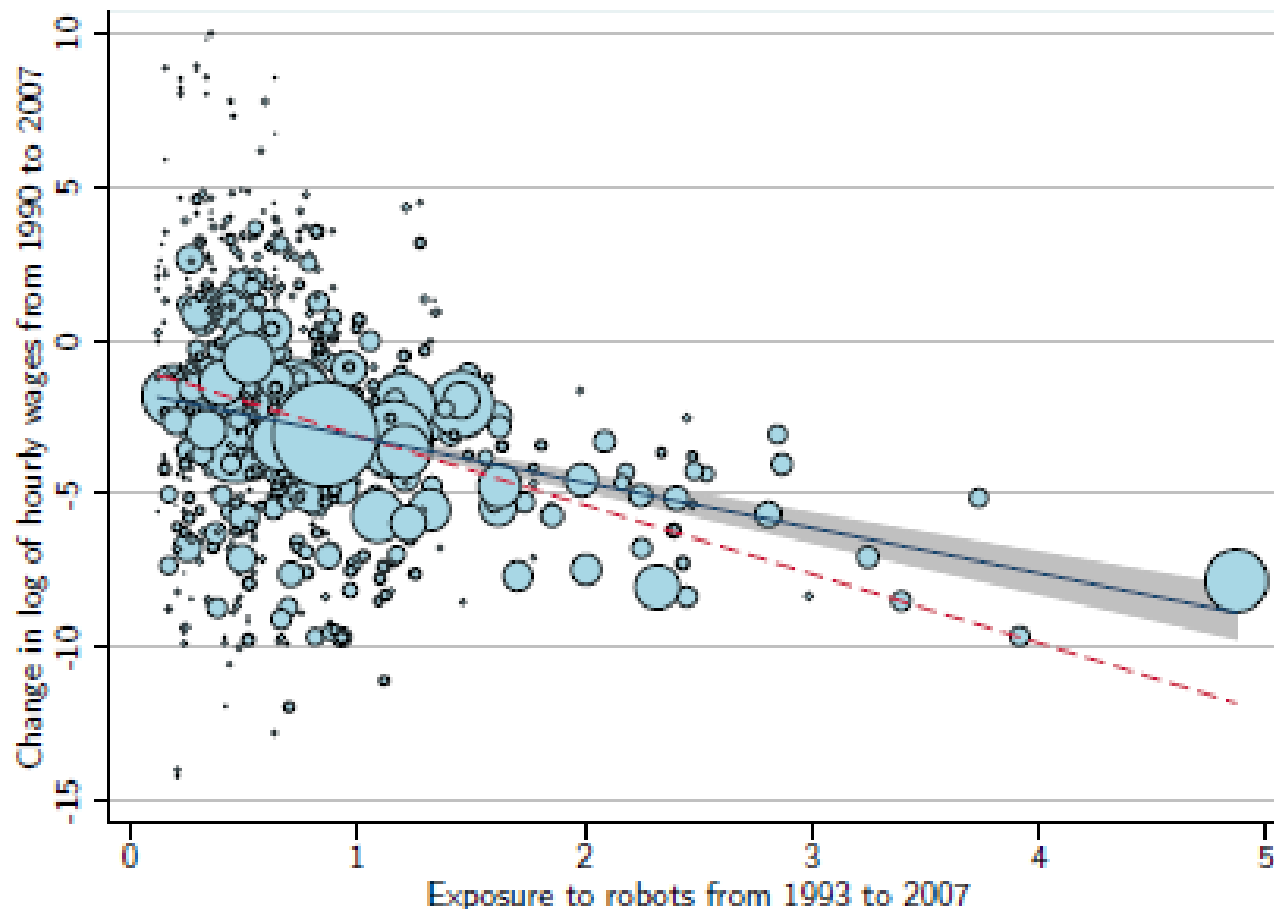**Figure 8:** Relationship between the exposure to robots and wages, Cont'd

Note: The figure shows the residual plot of the change in the log of wages (hourly wages in the top panel; weekly wages in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The red dot line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

Note: The figure shows the residual plot of the past change in employment and wages between 1970 and 1990 (Census private employment to population ratio in the top panel; log of hourly wage in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

Figure 9: Placebo checks, Cont'd

Note: The figure shows the residual plot of the past change in employment and wages between 1970 and 1990 (Census private employment to population ratio in the top panel; log of hourly wage in the bottom panel) against the exposure to robots between 1993 and 2007 after the covariates in column 4 of Table 2 have been partialled out. In both panels, the solid line shows the regression coefficient from a weighted regression with commuting zone working-age population in 1990 as weights. The dotted (red) line shows the weighted regression coefficient after the top 1% of the commuting zones with the highest exposure to robots is excluded. Marker size indicates the share of the 1990 US working age population in the corresponding commuting zone.

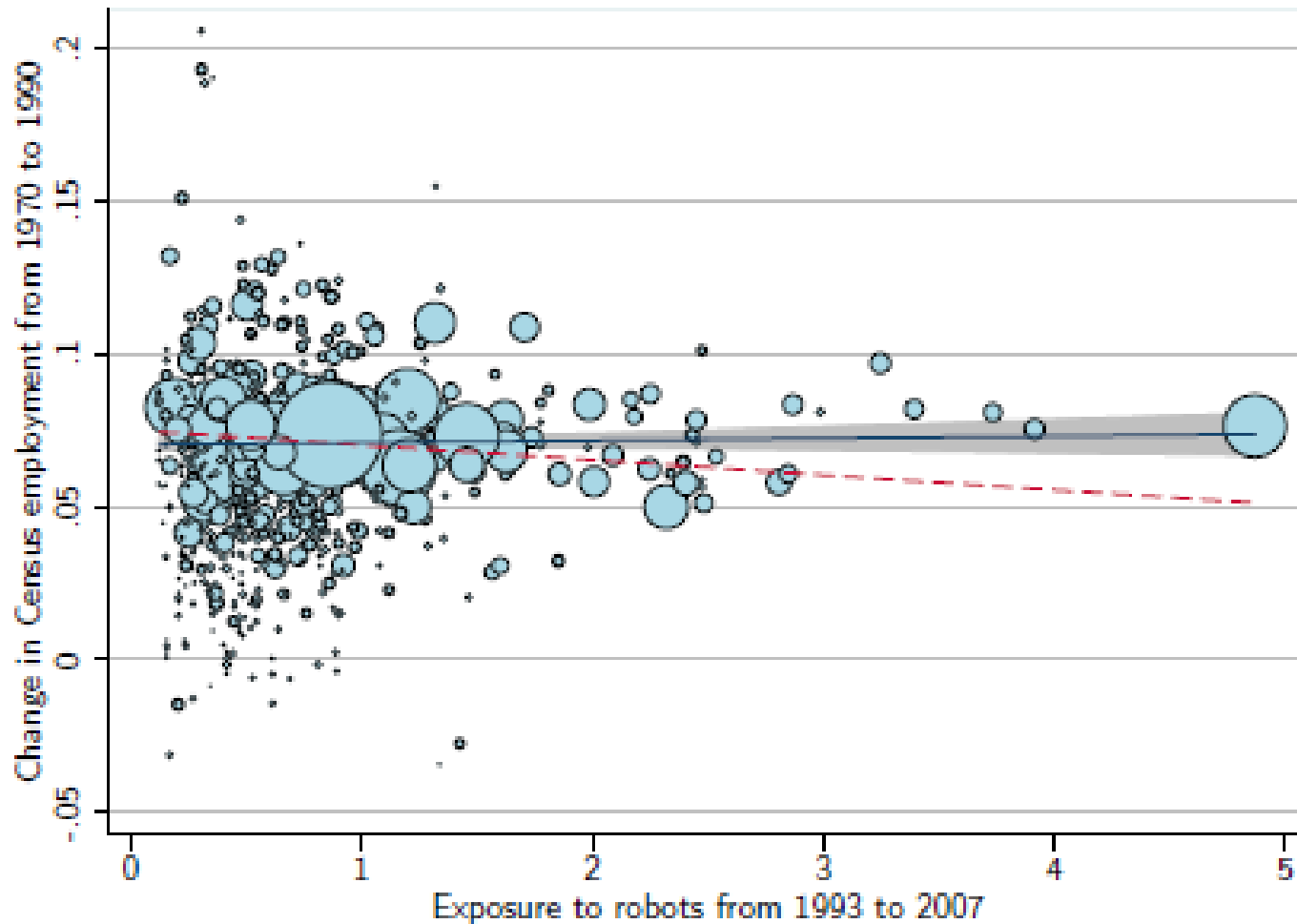# Figure 10: Relationship between the exposure to robots and industry employment
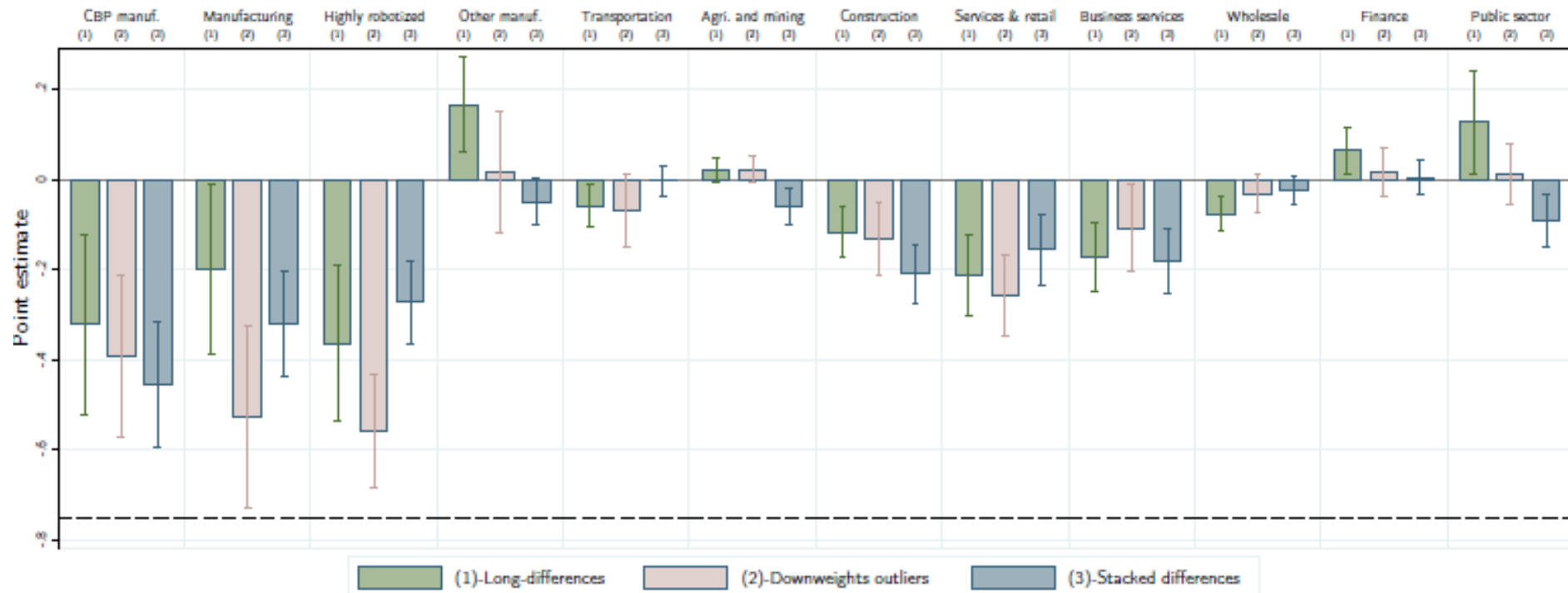
Note: The figure shows the estimates of the change in industry employment to population ratio against the exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The green bars correspond to a long-differences specification similar to column 4 of Table 2; The rose bars correspond to a long-differences specification similar to column 6 of Table 2, in which we downweigh outliers; the blue bars correspond to a stacked-differences specification similar to column 2 of Table 3. For comparison, we also indicate with a dashed horizontal line the magnitude of the effect on Census private employment to population ratio.

Figure 11: Relationship between the exposure to robots and occupation employment
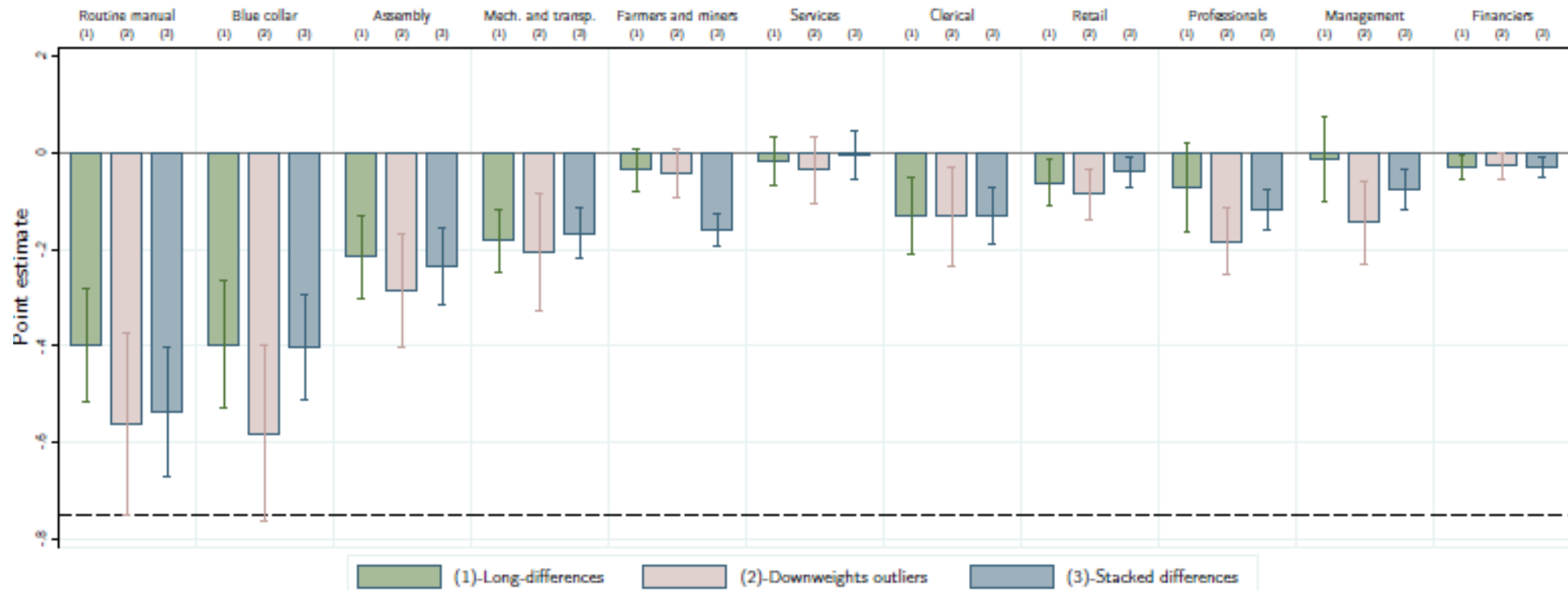
Note: The figure shows the estimates of the change in occupation employment to population ratio against the exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The green bars correspond to a long-differences specification similar to column 4 of Table 2; The rose bars correspond to a long-differences specification similar to column 6 of Table 2, in which we downweigh outliers; the blue bars correspond to a stacked-differences specification similar to column 2 of Table 3. For comparison, we also indicate with a dashed horizontal line the magnitude of the effect on Census private employment to population ratio.

Figure 12: Relationship between the exposure to robots and employment and wages by education group
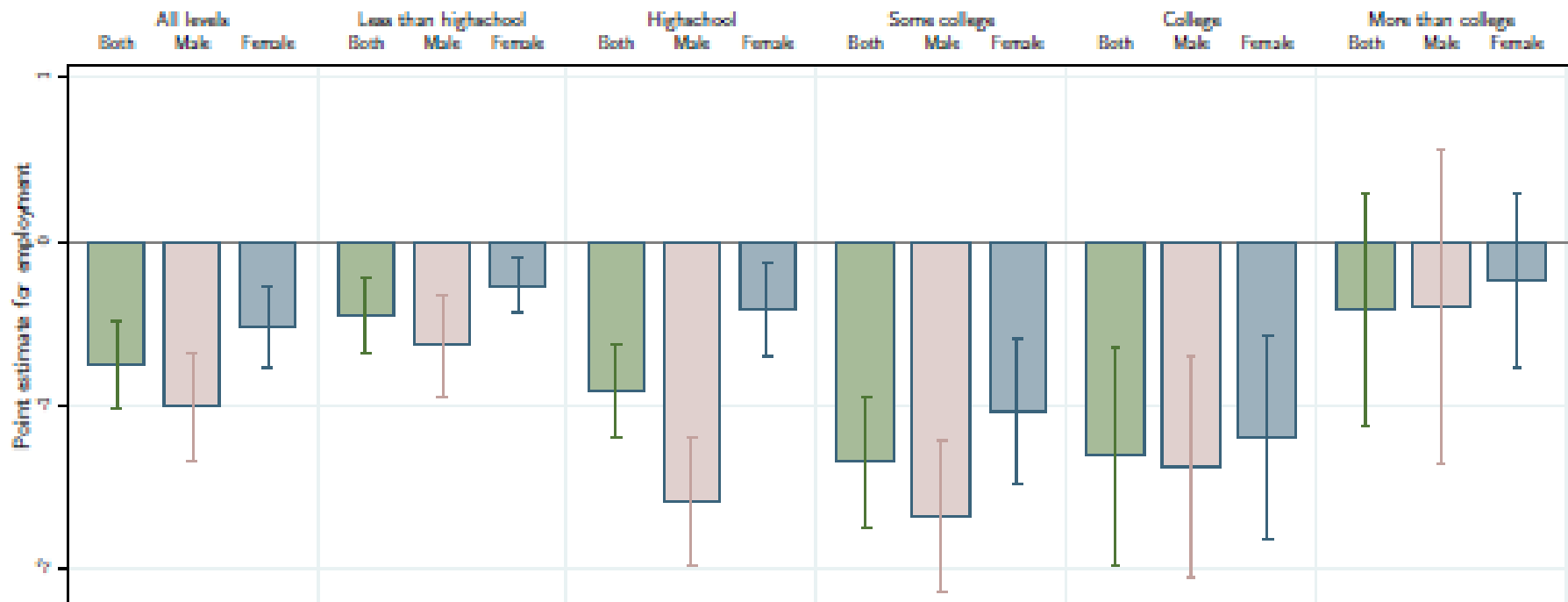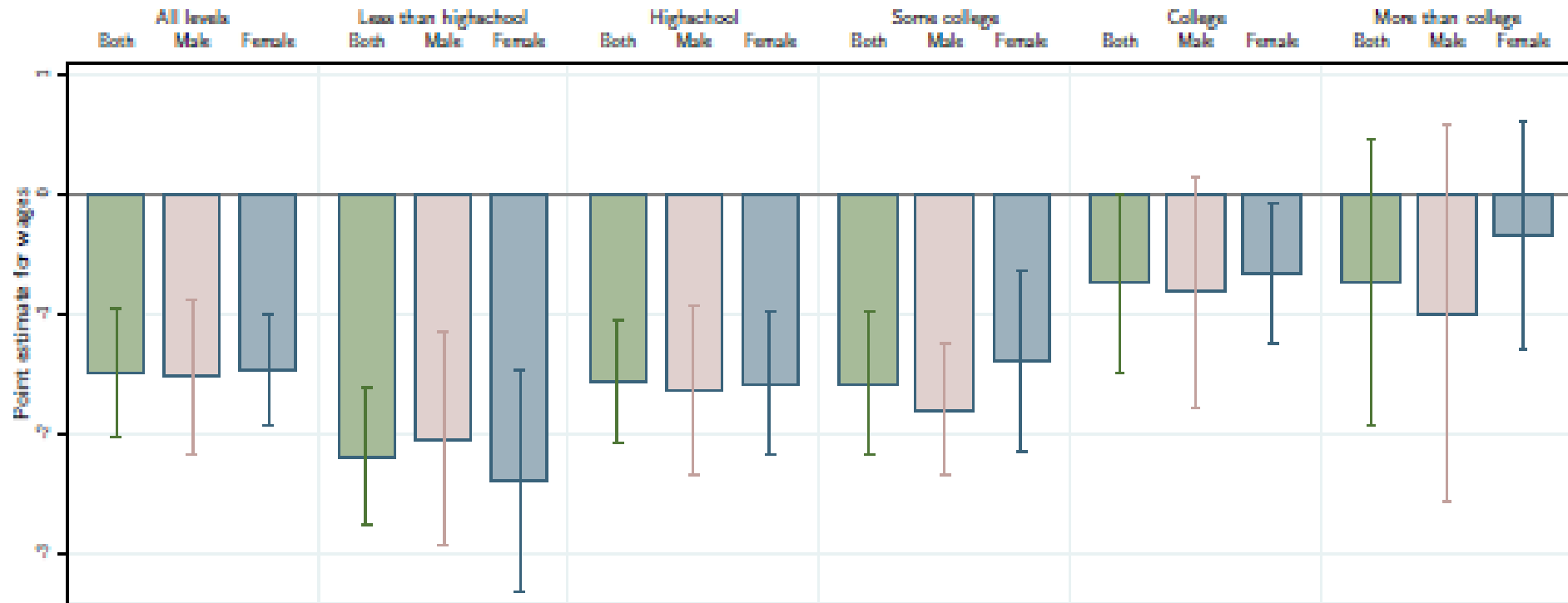
Note: The figure shows the estimates of the change in Census private employment to population ratio (top panel) and log of hourly wage (bottom panel) against the (exogenous) exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The figure shows the estimates separately by education level and gender. The top panel indicates the education level. For each level we present our baseline estimates (analogous to those in column 4 in Table 2) for all people, men and women.

Note: The figure shows the estimates of the change in Census private employment to population ratio (top panel) and log of hourly wage (bottom panel) against the (exogenous) exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The figure shows the estimates separately by education level and gender. The top panel indicates the education level. For each level we present our baseline estimates (analogous to those in column 4 in Table 2) for all people, men and women.

Figure 13: Relationship between the exposure to robots and the wage distribution
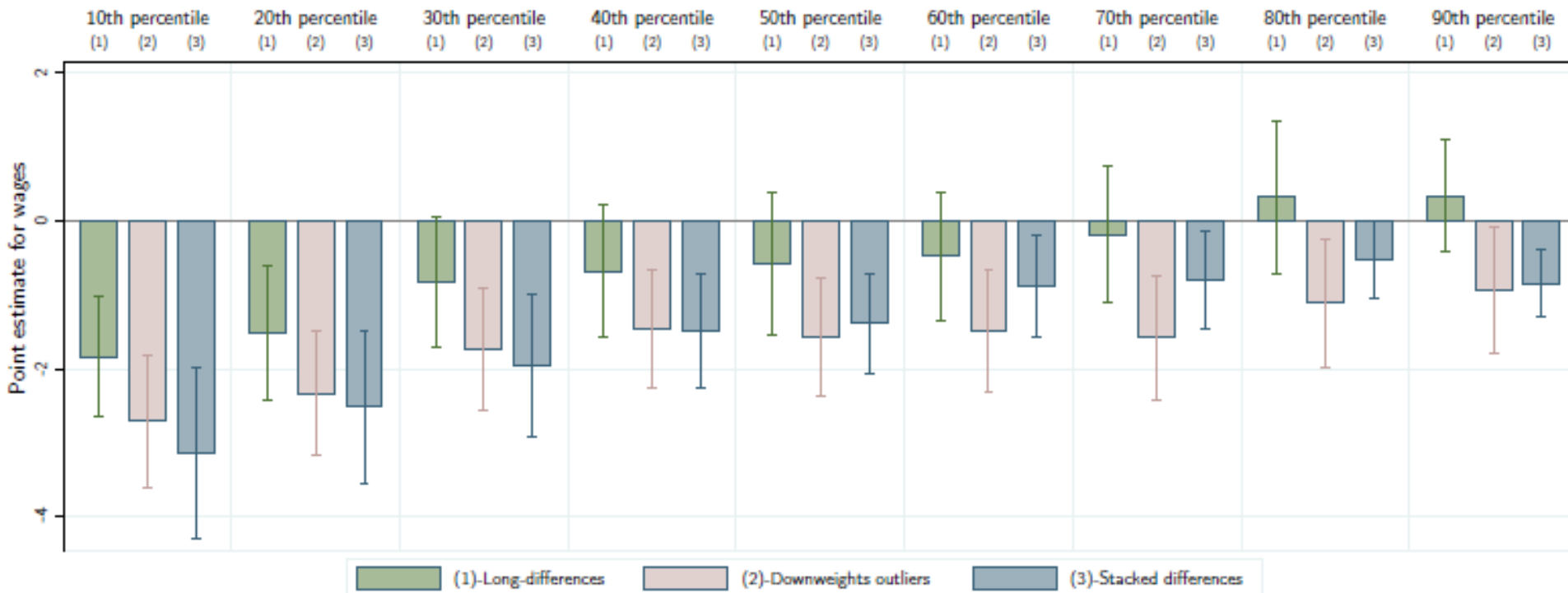
Note: The figure shows the estimates of the change in the 10th, 20th, . . . , and 90th wage deciles against the (exogenous) exposure to robots between 1993 and 2007 conditional on the covariates in column 4 of Table 2. The green bars correspond to a long-differences specification similar to column 4 of Table 2; The rose bars correspond to a long-differences specification similar to column 6 of Table 2, in which we downweigh outliers; the blue bars correspond to a stacked-differences specification similar to column 2 of Table 3.

Table 1: Summary statistics

	ALL ZONES $N = 722$	QUARTILES OF THE CHANGE IN EXPOSURE TO ROBOTS			
		Q1 $N = 304$	Q2 $N = 202$	Q3 $N = 129$	Q4 $N = 87$
		Panel A. Outcomes			
Census private employment to population ratio in 1990	0.354	0.317	0.357	0.363	0.376
	[0.044]	[0.039]	[0.049]	[0.035]	[0.029]
CBP employment to population ratio in 1990	0.381	0.336	0.390	0.389	0.408
	[0.074]	[0.070]	[0.084]	[0.063]	[0.057]
Change in Census private employment to population ratio from 1990 to 2007 (in p.p.)	0.294	1.486	0.418	-0.599	-0.117
	[2.240]	[2.336]	[2.271]	[2.208]	[1.564]
Change in CBP employment to population ratio from 1990 to 2007 (in p.p.)	2.002	3.627	2.592	0.740	1.074
	[3.791]	[4.880]	[3.275]	[3.547]	[2.419]
Change of Census log employment from 1990 to 2007 (in p.p.)	18.688	27.132	21.978	15.191	10.844
	[14.838]	[16.894]	[15.213]	[11.001]	[9.613]
Change of CBP log employment from 1990 to 2007 (in p.p.)	23.208	32.942	27.559	18.919	13.857
	[17.439]	[21.023]	[16.549]	[13.146]	[10.871]
Hourly wages in 1990	15.609	15.493	14.979	15.862	16.096
	[2.493]	[3.055]	[2.364]	[2.337]	[2.004]
Change in the log of hourly wages from 1990 to 2007 (in p.p.), adjusted for composition	-3.844	-1.803	-1.871	-5.397	-6.236
	[4.552]	[5.354]	[4.381]	[3.241]	[2.969]
Change in the log of weekly wages from 1990 to 2007 (in p.p.), adjusted for composition	-5.252	-2.047	-3.480	-7.236	-8.135
	[5.210]	[5.456]	[4.885]	[3.791]	[3.922]

Note: Sample means and standard deviations (in brackets) for the entire sample of commuting zones and by (population- weighted) quartiles of the exposure to robots distribution. Panel A includes our main outcome variables, while Panel B is for the main covariates. See text for variable definitions and sources.

Table 1: Summary statistics, Cont'd

		QUARTILES OF THE CHANGE IN EXPOSURE TO ROBOTS			
	ALL ZONES	Q1	Q2	Q3	Q4
	$N = 722$	$N = 304$	$N = 202$	$N = 129$	$N = 87$
		Panel B. Covariates			
Share of employment in manufacturing 1990	0.225	0.150	0.233	0.252	0.262
	[0.079]	[0.053]	[0.073]	[0.073]	[0.062]
Share of employment in durables 1990	0.136	0.085	0.135	0.153	0.167
	[0.059]	[0.036]	[0.044]	[0.049]	[0.066]
Exposure to Chinese imports from 1990 to 2007	3.363	2.229	3.667	4.165	3.392
	[2.059]	[1.296]	[2.205]	[2.322]	[1.782]
Share of employment in routine jobs 1990	0.346	0.339	0.340	0.347	0.357
	[0.026]	[0.032]	[0.025]	[0.020]	[0.020]
Exposure to offshoring from 1993 to 2007	0.073	0.048	0.082	0.094	0.068
	[0.083]	[0.061]	[0.095]	[0.103]	[0.059]
Exposure to Mexican imports from 1991 to 2007	1.863	1.005	1.756	1.958	2.678
	[1.731]	[0.850]	[1.821]	[1.012]	[2.304]
Share of working-age population in 1990	0.658	0.651	0.659	0.663	0.658
	[0.025]	[0.035]	[0.027]	[0.020]	[0.015]
Share of population with college in 1990	0.193	0.196	0.200	0.187	0.190
	[0.056]	[0.063]	[0.064]	[0.050]	[0.047]

Note: Sample means and standard deviations (in brackets) for the entire sample of commuting zones and by (population- weighted) quartiles of the exposure to robots distribution. Panel A includes our main outcome variables, while Panel B is for the main covariates. See text for variable definitions and sources.

Table 2: The impact of the exposure to robots on employment and wages (long differences)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	ESTIMATES FOR EMPLOYMENT AND WAGES FROM 1990 TO 2007						
Panel A. Census private employment to population ratio.							
Exposure to robots from 1993 to 2007	-0.916***	-0.782***	-0.769***	-0.751***	-1.125***	-1.096***	-1.330***
	(0.304)	(0.262)	(0.185)	(0.166)	(0.264)	(0.234)	(0.368)
Observations	722	722	722	722	722	721	714
Panel B. CBP employment to population ratio.							
Exposure to robots from 1993 to 2007	-1.435***	-1.175***	-1.231***	-1.310***	-1.118***	-1.018***	-1.899**
	(0.503)	(0.377)	(0.372)	(0.347)	(0.410)	(0.327)	(0.883)
Observations	722	722	722	722	722	719	714
Panel C. Log hourly wage.							
Exposure to robots from 1993 to 2007	-2.273***	-1.941***	-1.409***	-1.476***	-1.950***	-2.107***	-2.253***
	(0.391)	(0.249)	(0.272)	(0.322)	(0.399)	(0.382)	(0.566)
Observations	163114	163114	163114	163114	163114	160027	160534
Panel D. Log weekly wage.							
Exposure to robots from 1993 to 2007	-2.982***	-2.562***	-2.068***	-2.126***	-2.527***	-2.593***	-2.791***
	(0.389)	(0.270)	(0.267)	(0.301)	(0.498)	(0.414)	(0.563)
Observations	163114	163114	163114	163114	163114	159657	160534
Covariates & sample restrictions:							
Census division dummies	✓	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓	✓
Trade, Routinization and Offshoring				✓	✓	✓	✓
Unweighted					✓		
Down-weights outliers						✓	
Removes highly exposed areas							✓

Table 3: The impact of the exposure to robots on employment and wages (stacked differences)

	(1)	(2)	(3)	(4)	(5)	(6)
	STACKED-DIFFERENCES ESTIMATES 1990-2000 AND 2000-2007					
	Panel A. Census private employment to population ratio.					
Exposure to robots	-0.951***	-0.953***	-1.384***	-1.346***	-1.249***	-0.613***
	(0.152)	(0.146)	(0.174)	(0.139)	(0.339)	(0.111)
Observations	1444	1444	1444	1441	1427	1444
	Panel B. CBP employment to population ratio.					
Exposure to robots	-1.891***	-1.958***	-1.877***	-1.695***	-2.459***	-1.922***
	(0.300)	(0.310)	(0.256)	(0.209)	(0.674)	(0.379)
Observations	1444	1444	1444	1436	1427	1444
	Panel C. Log hourly wage.					
Exposure to robots	-1.939***	-1.919***	-2.176***	-1.485***	-2.428**	-2.519***
	(0.342)	(0.375)	(0.513)	(0.436)	(0.918)	(0.489)
Observations	326377	326377	326377	318420	321643	326377
	Panel D. Log weekly wage.					
Exposure to robots	-3.266***	-3.200***	-3.979***	-2.471***	-4.117***	-3.734***
	(0.399)	(0.434)	(0.609)	(0.457)	(1.084)	(0.764)
Observations	326377	326377	326377	317850	321643	326377
Covariates & sample restrictions:						
Demographic, industry shares and census division dummies	✓	✓	✓	✓	✓	✓
Trade, routinization and offshoring		✓	✓	✓	✓	✓
Unweighted			✓			
Down-weights outliers				✓		
Removes highly exposed areas					✓	
Commuting zone fixed effects						✓

Table 4: IV estimates of the change in exposure to robots on employment and wages

	IV ESTIMATES FROM 1990 TO 2007						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. First-stage for exposure to robots in the US.							
Exposure to robots from 1993 to 2007	2.175***	2.178***	2.094***	2.026***	1.535***	1.536***	1.083***
	(0.285)	(0.272)	(0.269)	(0.275)	(0.257)	(0.255)	(0.135)
Observations	722	722	722	722	722	721	714
Panel B. Census private employment to population ratio.							
Instrumented exposure to robots from 1993 to 2007	-0.421**	-0.359**	-0.367***	-0.371***	-0.733***	-0.714***	-1.228***
	(0.180)	(0.155)	(0.123)	(0.115)	(0.210)	(0.193)	(0.395)
First-stage F statistic	58.3	64.2	60.6	54.2	35.7	36.3	64.2
Observations	722	722	722	722	722	721	714
Panel C. CBP employment to population ratio.							
Instrumented exposure to robots from 1993 to 2007	-0.660**	-0.540**	-0.588***	-0.647***	-0.728***	-0.647***	-1.754**
	(0.270)	(0.217)	(0.218)	(0.207)	(0.263)	(0.197)	(0.877)
First-stage F statistic	58.3	64.2	60.6	54.2	35.7	37.1	64.2
Observations	722	722	722	722	722	719	714

Table 4: IV estimates of the change in exposure to robots on employment and wages, Cont'd

	IV ESTIMATES FROM 1990 TO 2007						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel D. Log hourly wage.						
Instrumented exposure to robots	-1.043***	-0.891***	-0.675***	-0.732***	-1.259***	-1.274***	-2.062***
from 1993 to 2007	(0.257)	(0.196)	(0.173)	(0.219)	(0.337)	(0.352)	(0.471)
First-stage F statistic	60.4	66.2	61.4	55.5	34.5	25.9	68.3
Observations	163114	163114	163114	163114	163114	160027	160534
	Panel E. Log weekly wage.						
Instrumented exposure to robots	-1.368***	-1.176***	-0.991***	-1.054***	-1.631***	-1.571***	-2.555***
from 1993 to 2007	(0.286)	(0.229)	(0.179)	(0.226)	(0.409)	(0.414)	(0.457)
First-stage F statistic	60.4	66.2	61.4	55.5	34.5	25.7	68.3
Observations	163114	163114	163114	163114	163114	159657	160534
Covariates & sample restrictions:							
Census division dummies	✓	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓	✓
Trade, Routinization and Offshoring				✓	✓	✓	✓
Unweighted					✓		
Down-weights outliers						✓	
Removes highly exposed areas							✓

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	PLACEBO CHECKS USING OUTCOMES FOR 1970-1990						

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Census private employment to population ratio.							
Exposure to robots from 1993 to 2007	-0.046	0.040	0.141	0.070	-0.594	-0.398	-0.489
	(0.234)	(0.136)	(0.176)	(0.202)	(0.474)	(0.412)	(0.552)
Observations	722	722	722	722	722	718	714
Panel B. Log hourly wage.							
Exposure to robots from 1993 to 2007	-1.364**	-1.397*	-0.048	0.066	-0.545	0.189	2.418
	(0.646)	(0.743)	(1.044)	(0.964)	(1.506)	(0.882)	(1.577)
Observations	96487	96487	96487	96487	96487	94832	95109
Panel C. Log weekly wage.							
Exposure to robots from 1993 to 2007	-1.120*	-1.149	0.339	0.440	-0.236	0.519	1.982
	(0.658)	(0.687)	(1.000)	(0.934)	(1.623)	(0.873)	(1.763)
Observations	96487	96487	96487	96487	96487	94701	95109
Covariates & sample restrictions:							
Census division dummies	✓	✓	✓	✓	✓	✓	✓
Demographics		✓	✓	✓	✓	✓	✓
Broad industry shares			✓	✓	✓	✓	✓
Trade, Routinization and Offshoring				✓	✓	✓	✓
Unweighted					✓		
Down-weights outliers						✓	
Removes highly exposed areas							✓

Table 6: The impact of the exposure to robots on employment and wages (controlling for the automobile industry)

	ESTIMATES THAT CONTROL FOR CHANGES IN THE AUTO INDUSTRY					
	LONG-DIFFERENCES ESTIMATES			STACKED-DIFFERENCES ESTIMATES		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Census private employment to population ratio.						
Exposure to robots in other industries	-1.325***	-1.254***	-1.246***	-0.988**	-1.628***	-1.607***
	(0.363)	(0.342)	(0.283)	(0.464)	(0.414)	(0.326)
Exposure to robots in automotive manufacture	-0.653***	-1.029***	-0.993***	-0.945***	-1.220***	-1.162***
	(0.123)	(0.323)	(0.296)	(0.128)	(0.243)	(0.214)
Observations	722	722	721	1444	1444	1441
Panel B. CBP employment to population ratio.						
Exposure to robots in other industries	-1.839	-0.883	-0.502	-2.285*	-1.897***	-1.490***
	(1.175)	(0.629)	(0.447)	(1.235)	(0.696)	(0.530)
Exposure to robots in automotive manufacture	-1.220***	-1.292**	-1.338***	-1.884***	-1.863***	-1.819***
	(0.279)	(0.483)	(0.434)	(0.224)	(0.335)	(0.282)
Observations	722	722	718	1444	1444	1436

| | ESTIMATES THAT CONTROL FOR CHANGES IN THE AUTO INDUSTRY | | | | | |
| | LONG-DIFFERENCES ESTIMATES | | | STACKED-DIFFERENCES ESTIMATES | | |
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel C. Log hourly wage.					
Exposure to robots in other	-1.948**	-2.269***	-1.846***	-1.800	-2.182**	-0.614
industries	(0.730)	(0.781)	(0.646)	(1.285)	(1.000)	(0.789)
Exposure to robots in automotive	-1.395***	-1.726***	-2.243***	-1.946***	-2.172***	-1.920***
manufacture	(0.278)	(0.441)	(0.387)	(0.309)	(0.465)	(0.383)
Observations	163114	163114	160030	326377	326377	318414
	Panel D. Log weekly wage.					
Exposure to robots in other	-2.136***	-2.801***	-2.302***	-3.252**	-4.264***	-1.611
industries	(0.663)	(1.000)	(0.648)	(1.585)	(1.427)	(1.014)
Exposure to robots in automotive	-2.124***	-2.334***	-2.745***	-3.189***	-3.795***	-2.907***
manufacture	(0.289)	(0.536)	(0.427)	(0.372)	(0.520)	(0.438)
Observations	163114	163114	159658	326377	326377	317853
Covariates & sample restrictions:						
Baseline covariates	✓	✓	✓	✓	✓	✓
Unweighted		✓			✓	
Down-weights outliers			✓			✓

	ESTIMATES THAT CONTROL FOR OTHER TRENDS					
	EMPLOYMENT TO POPULATION			LOG HOURLY WAGE		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A. Control for the decline of industries from 1970 to 1990					
Exposure to robots from 1993 to 2007	-0.641***	-0.965***	-0.923***	-1.310***	-1.698***	-1.830***
	(0.156)	(0.254)	(0.221)	(0.311)	(0.394)	(0.347)
Exposure to industries in decline from 1970 to 1990	-0.229***	-0.277***	-0.285***	-0.352***	-0.436***	-0.460***
	(0.065)	(0.080)	(0.072)	(0.121)	(0.144)	(0.084)
Observations	722	722	721	163114	163114	160022
	Panel B. Control for the use of capital in different industries					
Exposure to robots from 1993 to 2007	-0.674***	-1.111***	-1.073***	-1.385***	-1.877***	-1.921***
	(0.146)	(0.263)	(0.234)	(0.303)	(0.419)	(0.384)
Exposure to capital from 1990 to 2007	3.132**	0.436	0.875	3.660*	2.230	5.207***
	(1.437)	(1.164)	(0.978)	(2.110)	(2.599)	(1.708)
Observations	722	722	721	163114	163114	160022
	Panel C. Control for the use of computers at work across commuting zones					
Exposure to robots from 1993 to 2007	-0.743***	-1.075***	-1.058***	-1.491***	-2.035***	-2.153***
	(0.165)	(0.260)	(0.234)	(0.321)	(0.404)	(0.388)
Change in number of computers per worker from 1990 to 2006	0.341*	0.090	0.066	-0.629**	-0.737**	0.001
	(0.194)	(0.193)	(0.161)	(0.300)	(0.280)	(0.157)
Observations	696	696	695	159411	159411	156390
Covariates & sample restrictions:						
Baseline covariates	✓	✓	✓	✓	✓	✓
Unweighted		✓			✓	
Down-weights outliers			✓			✓

	LONG-DIFFERENCES ESTIMATES			STACKED-DIFFERENCES ESTIMATES		
	(1)	(2)	(3)	(4)	(5)	(6)
	ESTIMATES FOR MEN					
	Panel A. Census private employment to population ratio.					
Change in exposure to robots from 1993 to 2007	-1.007***	-1.416***	-1.316***	-1.049***	-1.709***	-1.699***
	(0.198)	(0.315)	(0.280)	(0.182)	(0.208)	(0.164)
Observations	722	722	720	1444	1444	1442
	Panel B. Log hourly wage.					
Exposure to robots from 1993 to 2007	-1.518***	-1.826***	-2.297***	-1.952***	-1.945***	-1.473**
	(0.393)	(0.453)	(0.384)	(0.430)	(0.588)	(0.551)
Observations	80930	80930	79453	162106	162106	158267
	ESTIMATES FOR WOMEN					
	Panel C. Census private employment to population ratio.					
Change in exposure to robots from 1993 to 2007	-0.522***	-0.869***	-0.881***	-0.856***	-1.063***	-1.052***
	(0.147)	(0.243)	(0.208)	(0.122)	(0.175)	(0.144)
Observations	722	722	721	1444	1444	1442
	Panel D. Log hourly wage.					
Exposure to robots from 1993 to 2007	-1.457***	-2.095***	-1.950***	-1.900***	-2.423***	-1.518***
	(0.287)	(0.496)	(0.488)	(0.322)	(0.546)	(0.380)
Observations	82184	82184	80540	164271	164271	160146
Covariates & sample restrictions:						
Baseline covariates	✓	✓	✓	✓	✓	✓
Unweighted		✓			✓	
Down-weights outliers			✓			✓

	MODELS IN LEVELS				MODELS IN LOGS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DATA FROM THE BEA							
	Panel A. Total income.							
Change in exposure to robots from 1993 to 2007	-169.350	-228.797	-747.209**	-673.540	-1.841***	-2.458**	-2.815***	-2.704**
	(239.508)	(466.035)	(336.641)	(552.959)	(0.520)	(1.199)	(0.847)	(1.166)
Observations	722	722	713	714	722	722	715	714
	Panel B. Wage income.							
Change in exposure to robots from 1993 to 2007	-605.314*	-422.293	-734.602**	-1517.846**	-2.688***	-3.397**	-3.757***	-5.036***
	(334.307)	(318.826)	(289.337)	(627.278)	(0.855)	(1.322)	(1.165)	(1.502)
Observations	722	722	715	714	722	722	719	714
	Panel C. Non-wage income.							
Change in exposure to robots from 1993 to 2007	435.953	193.496	-234.250**	844.306	0.383	-1.201	-1.425	1.780
	(299.851)	(323.711)	(112.478)	(555.366)	(1.309)	(1.438)	(1.029)	(3.143)
Observations	722	722	706	714	721	721	713	713
	DATA FROM THE IRS							
	Panel D. Total income.							
Change in exposure to robots from 1993 to 2007	120.673	-115.604	-345.401*	-159.057	-1.618***	-1.961*	-2.164**	-2.402**
	(148.264)	(242.298)	(195.813)	(313.112)	(0.430)	(1.020)	(0.891)	(0.932)
Observations	722	722	714	714	722	722	714	714
	Panel E. Wage income.							
Change in exposure to robots from 1993 to 2007	-15.643	-204.039	-476.333***	-157.722	-1.910***	-2.512**	-2.842***	-2.897***
	(100.845)	(187.578)	(171.103)	(221.908)	(0.428)	(0.966)	(0.835)	(0.966)
Observations	722	722	718	714	722	722	721	714
	Panel F. Non-wage income.							
Change in exposure to robots from 1993 to 2007	135.316*	88.435	-34.301	-1.335	-0.391	0.141	0.612	-1.084
	(72.716)	(161.154)	(83.917)	(139.083)	(0.743)	(1.831)	(1.464)	(1.837)
Observations	722	722	698	714	722	722	711	714
Covariates & sample restrictions:								
Baseline covariates	✓	✓	✓	✓	✓	✓	✓	✓
Unweighted		✓				✓		
Down-weights outliers			✓				✓	
Removes highly exposed areas				✓				✓