Automatic Reaction – What Happens to Workers at Firms that Automate?

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Longstanding concern: Automation threatens work

1. Luddites—Skilled weavers in the 19th century
2. U.S. Labor Secretary James Davis in 1927
3. Lyndon Johnson 1964 “Blue-Ribbon Presidential Commission on Technology, Automation, and Economic Progress”
4. Wassily Leontief in 1982:
   Role of workers will diminish — like horses
5. At present

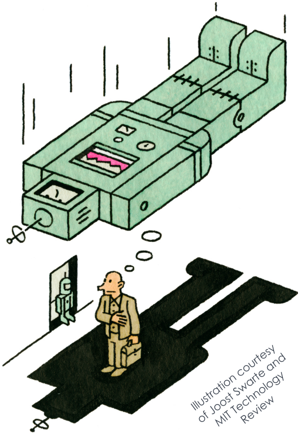


Illustration courtesy of Joost Swarte and MIT Technology Review

Automation and work

- **Theory**: **automation** technologies are **labor-replacing** – may lead to labor displacement even in aggregate
    - Autor-Levy-Murnane '03, Acemoglu-Autor '11, Acemoglu-Restrepo '18, Benzell-Kotlikoff-Lagarda-Sachs '18, Martinez '19, Susskind '17
- **Existing empirical evidence** on automation studies the (mostly aggregate) impact of the adoption of **robots** (mostly in manufacturing sectors):
    - Acemoglu-Restrepo '18, Dauth-Findeisen-Suedekum-Woessner '18, Graetz-Michaels '18, Koch-Manuylov-Smolka '19
- Lack empirical evidence on **how automation impacts individual workers**

Contributions of this paper

- Examine **worker-level impacts** of automation
- Directly measure **firm-level automation** expenditures across **all private non-financial sectors**
- Exploit the timing of **automation events** at the firm level for empirical identification
- **Compare** the worker impacts of **automation and computerization**

Preview of main findings

1. Automation leads to **displacement** for incumbent workers
    - Firm separation $\uparrow \rightarrow$ Non-employment $\uparrow \rightarrow$ **Annual earnings** $\downarrow$
    - **No wage scarring**, but earnings losses only partially offset by benefits
2. Affected workers more likely to **switch industries** and enter **early retirement**
3. Effects are **pervasive** across industries and worker types
4. Automation appears to be **more labor-displacing than computerization**

Agenda

1. Introduction
2. Data
3. Empirical approach
4. Worker-level impacts
5. Firm-level changes
6. Automation versus computerization
7. Conclusions

Agenda

Data sources from Statistics Netherlands

- Annual **survey of private non-financial firms** (covers all firms with >50 employees and samples smaller firms) which includes a question on **automation costs**
- Administrative daily **matched employer-employee records**
- Years **2000-2016**
- **36K unique firms** with at least 3 yrs of automation cost data employing **4.9M workers** annually on average

▸ Data cleaning

Automation costs

- Automation costs are an **official bookkeeping entry**
- Defined as costs of **third-party automation services**
  - Includes expenditures on custom software (excl. licensing costs for pre-packaged software)
  - Don't know the specific technology but includes self-service check-out, warehouse and storage systems, automated customer service, data-driven decision making, robot integrators, ...
- Expenditures at the **firm level** and in **all (non-financial private) sectors**

Agenda

Firm-level automation cost distributions

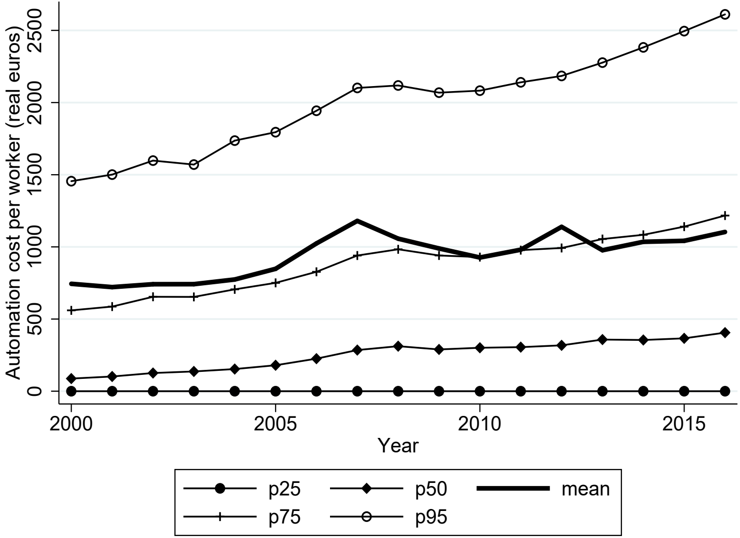
	Total cost cost (€)	Cost per worker (€)	Cost share (%)
p5	0	0	0
p10	0	0	0
p25	0	0	0
p50	10,508	257	0.15
p75	48,000	899	0.47
p90	175,083	2,058	1.05
p95	412,945	3,305	1.69
mean	**192,390**	**953**	**0.44**
mean excl. zeros	**280,703**	**1,391**	**0.64**
N firms × years		240,337	
N with 0 costs		31%	

Mean firm-level automation costs by sector

▸ by firm size

Sector	Cost per worker (€)	Cost share (%)	*N Firm x yr*
Manufacturing	986	0.36	44,636
Construction	415	0.20	28,774
Wholesale & retail trade	1,075	0.31	75,421
Transportation & storage	834	0.42	21,235
Accommodation & food serving	220	0.29	6,761
Information & communication	1,636	0.85	16,854
Prof'l, scientific, & techn'l act's	1,174	1.02	23,692
Admin & support act's	761	0.49	22,964

Automation costs per worker over time



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Defining automation spikes

- Firm j has **automation cost share spike** in year τ if its real automation costs $AC_{j\tau}$ relative to real total operating costs (excl. automation costs) averaged across all years are at least thrice the average firm-level cost share (excluding year τ):

$$spike_{j\tau} = \mathbb{1}\left\{\frac{AC_{j\tau}}{\overline{TC}_{j,t}} \geq 3 \times \frac{\overline{AC}_{j,t\neq\tau}}{\overline{TC}_{j,t}}\right\}$$

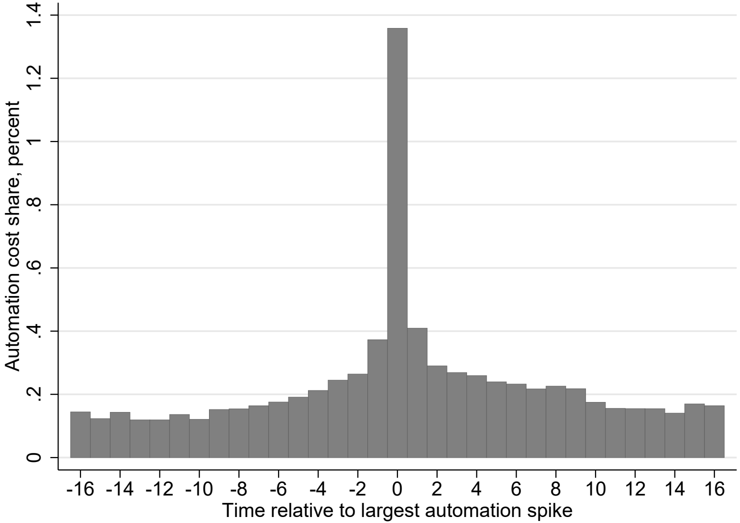
  where $\mathbb{1}\{\ldots\}$ denotes the indicator function

- **Firm-specific measure**: identifies automation events that are large for the firm, independent of firm's initial automation expenditure level

Automation spike frequencies

Spike frequency over 2000-2016	N firms	% of N firms
0	26,015	71.3
1	8,411	23.0
2	1,764	4.8
3	267	0.7
4	30	0.1
5	4	0.0
Total	36,491	100.0

Automation cost shares for spikers: spikes are events



Why do firms experience automation spikes?

- Spikes → **investment is lumpy**: significant share of investment occurs in episodes of disproportionately large quantities
- Spikes arise when investment is **irreversible** and there are **indivisibilities**
  - Under uncertainty, irreversibility creates option value to waiting (Pindyck '91, Nilsen-Schiantarelli '03)
  - Indivisibilities arise from fixed adjustment costs (Cooper-Haltiwanger-Power '99, Doms-Dunne '98, Rothschild '71).
- Major **automation** investments likely include:
  - Substantial **irreversible investments** in custom software and training;
  - **Fixed adjustment costs** from reorganizing production.

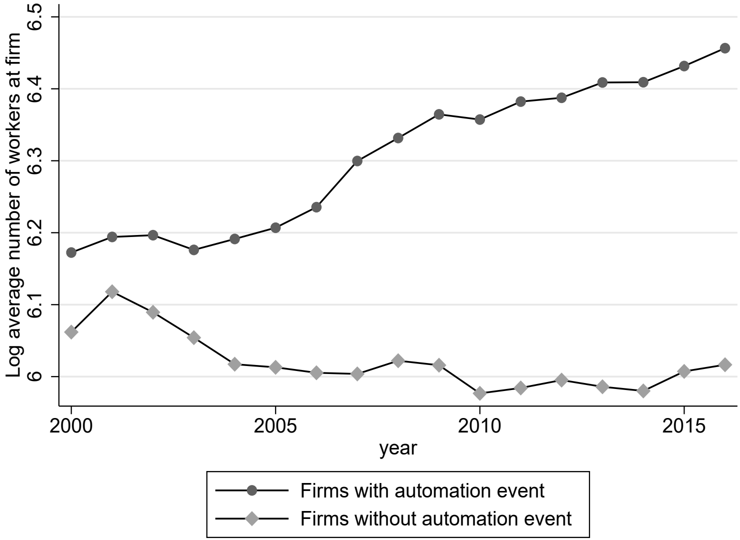
Agenda

How do firms with automation spikes differ?

	Mean automation cost:		
Firm type	level (€)	per worker (€)	share (%)
No automation spike	245,070	1,389	0.62
$\geq$1 automation spike	359,797	2,547	1.29

for 36K firms with at least 3 yrs of automation cost data

Log number of employees



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Leveraging automation cost spikes for identification

- Automation cost spikes are a **big event** for the firm (no "run-of-the-mill" automation), aiding identification
- Assume **timing of automation spikes is random** (conditional on observables) **for incumbent workers**
  - *Related event study approaches*: Borusyak-Jaravel '18; Duggan-Garthwaite-Goyal '16; Fadlon-Nielsen '17; He '18; Miller '17; Lafortune-Rothstein-Schanzenbach '18; Dobkin-Finkelstein-Kluender-Notowidigdo '18
  - Uncertainty & indivisibility $\rightarrow$ small Δ in payoff to automating can generate substantial Δ in the timing of investment (Bessen '99)

Defining treatment and controls

- Incumbent workers at a firm are **treated** in year τ if that firm undergoes an automation spike in year τ
- Incumbent workers employed at firms that spike at $\tau + k$ or later are used as **controls** for the years $\tau - k - 1$, where we choose $k = 5$
- Define **incumbent workers**: ≥ 3 yrs of firm tenure prior to the automation event (cf. mass lay-off literature)
- **Matching** controls and treated on pre-treatment income, sector, and calendar year (using CEM, see Blackwell-Iacus-King-Porro '09, Iacus-King-Porro '12) ▸ Matching details

Empirical model

Estimating equation:

$$y_{ijt} = \alpha + \beta F_i + \sum_{t \neq -1; t=-3}^{4} \gamma_t \times I_t + \sum_{t \neq -1; t=-3}^{4} \boldsymbol{\delta_t} \times I_t \times treat_i + \lambda X_{ijt} + \varepsilon_{ijt},$$

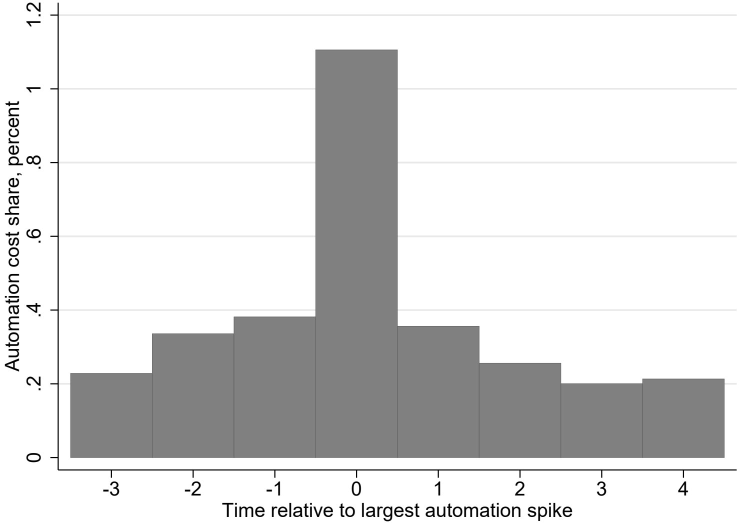
- i indexes workers, j firms, and t time measured relative to automation event in year τ, i.e. $t \equiv year - \tau$
- F_i is a **worker fixed-effect**
- I_t is a **time fixed-effect** relative to the event year, with $t \in \{-3, 4\}$, and $t = -1$ as reference category
- $treat_i$ is **treatment indicator** = 1 if worker i is employed at a firm experiencing an automation event at $t = 0$

Empirical model

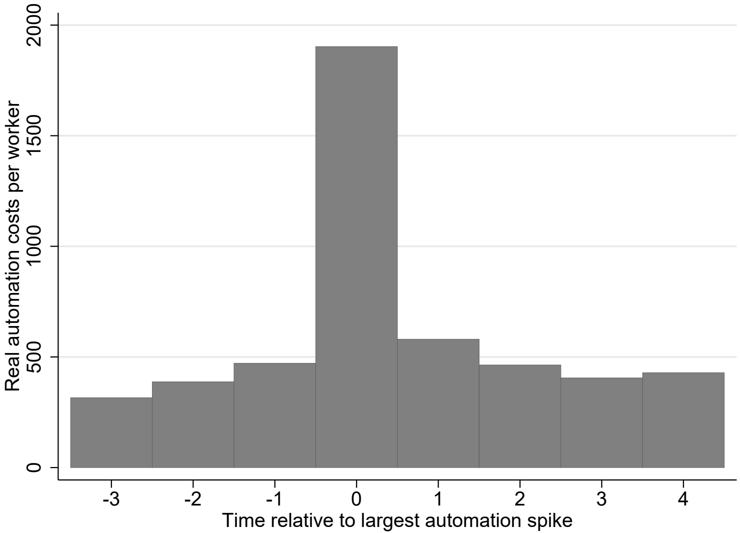
$$y_{ijt} = \alpha + \beta F_i + \sum_{t \neq -1; t=-3}^{4} \gamma_t \times I_t + \sum_{t \neq -1; t=-3}^{4} \boldsymbol{\delta_t} \times I_t \times treat_i + \lambda X_{ijt} + \varepsilon_{ijt},$$

- **Parameters of interest** are δ_t: period t treatment effect relative to pre-treatment period $t = -1$
- X_{ijt} are time-varying **controls**: worker age, age^2, year fixed effects
- **Standard errors** clustered at the treatment level (i.e. event windows for all workers employed at the same firm in $t - 1$ are one cluster)

Automation events for treated firms

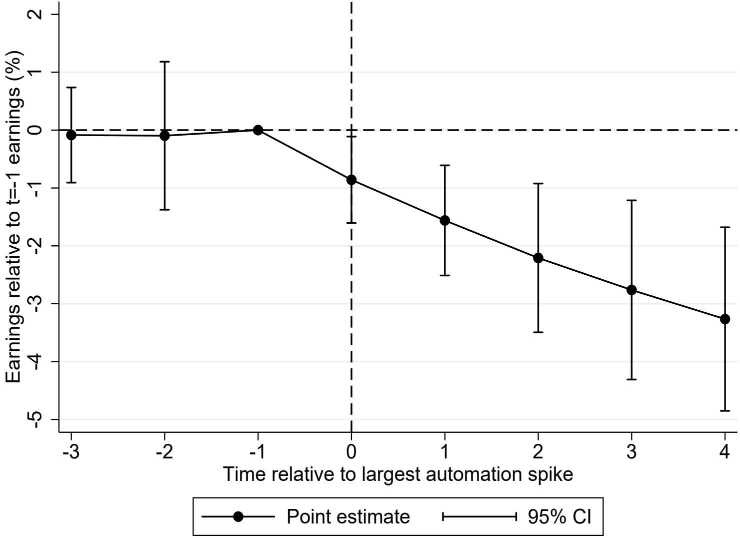


Automation events for treated firms

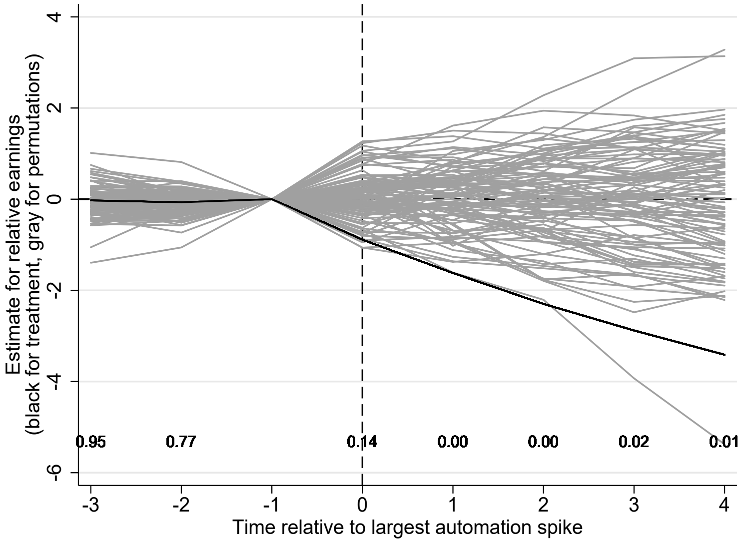


Agenda

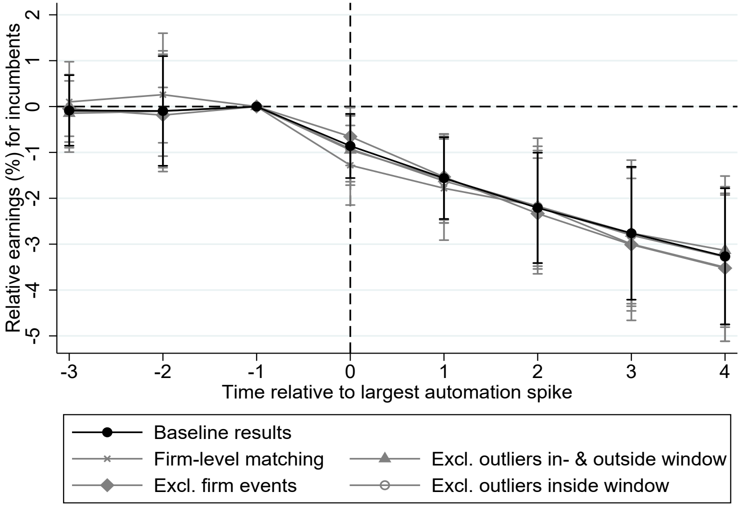
Annual wage income, percentages



Annual wage income (%): Randomization test



Robustness to other events: Annual wage income (%)



Robustness to changes in ▸ spike definition and ▸ model specification

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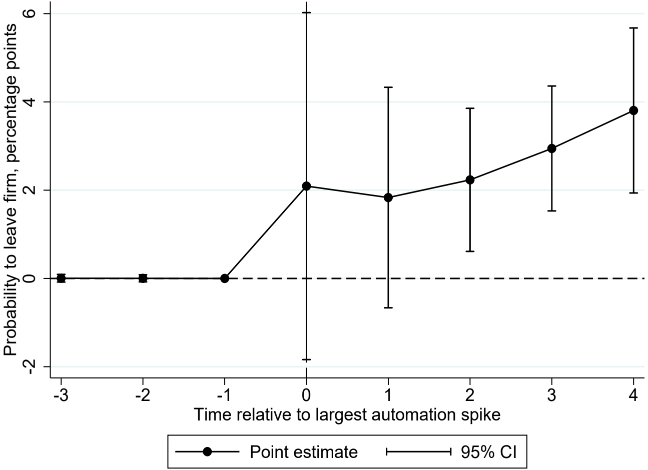
Firm separation, hazard rates

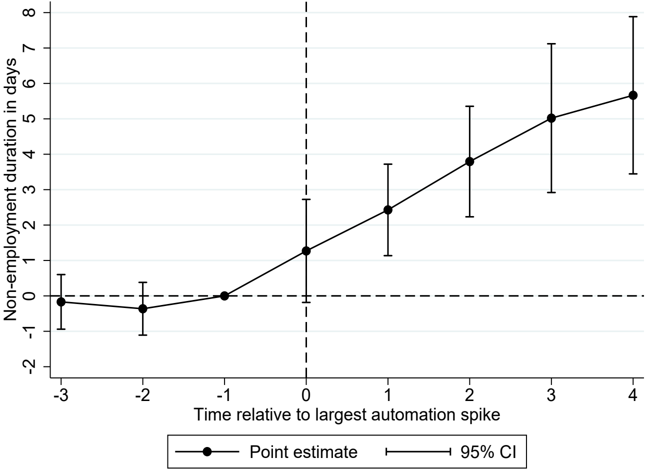
robustness



Hazard rates for CG incumbents are 9.6% in t=0 and 8.8% in t=4 (40%↑)

Annual days in non-employment

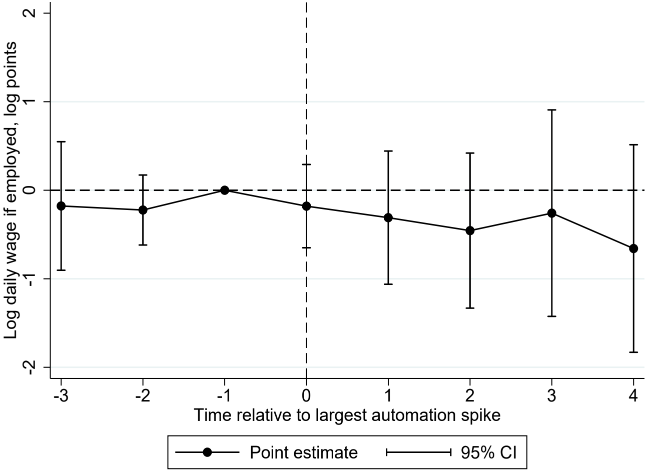
▸ robustness



Annual non-employment days for CG incumbents are 5.7 in t=0 and 28 in t=4 (20%↑)

Log daily wage

robustness

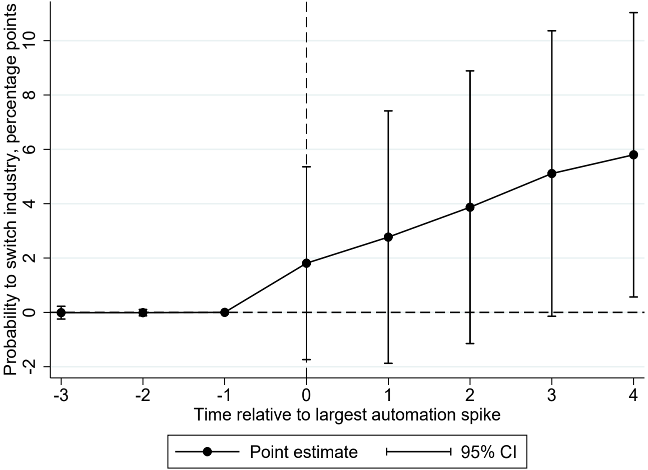


Wage change in log points for CG incumbents is 1.8 in t=0 and 5.4 in t=4

Agenda

1. Introduction
2. Data
3. Empirical approach
4. Worker-level impacts
   - Annual wage income
   - Firm separation, non-employment, and wage rates
   - Other adjustment margins and effect heterogeneity
5. Firm-level changes
6. Automation versus computerization
7. Conclusions

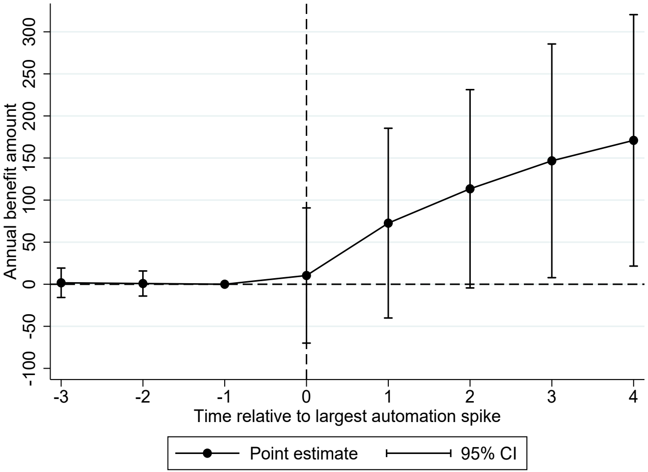
Probability of switching industries



Industry switch probability for CG incumbents is 7% in t=0 and 30% in t=4 (20%↑)

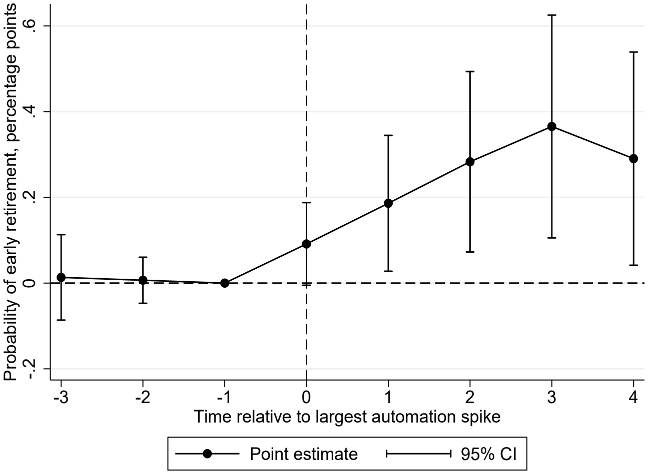
Annual total benefit income, levels

split by benefit source



Annual benefit income for CG incumbents is EUR 186 in t=0 and EUR 781 in t=4

Probability of early retirement



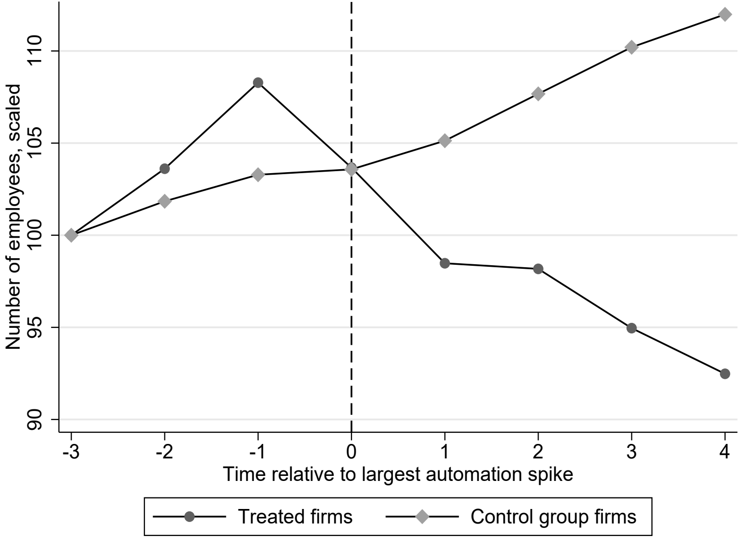
Early retirem. probability for CG incumbents is 0.2% in t=0 and 1.5% in t=4 (18%↑)

Effect heterogeneity

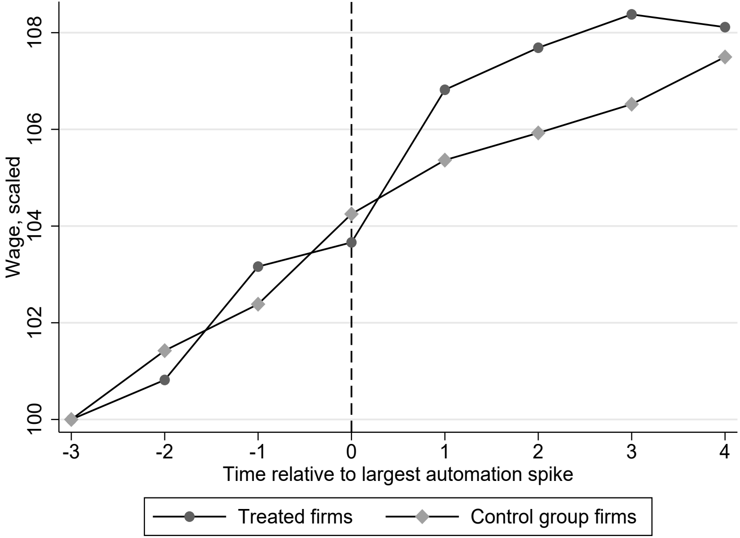
- Displacement effects for incumbent workers pervasive across: estimates
  - sectors (exception: Accommodation & food serving)
  - firm sizes
  - worker age & gender
  - workers' age-specific wage ranks ("skill level")
- No displacement effects for the firm's more recent pre-event hires
  estimates

Agenda

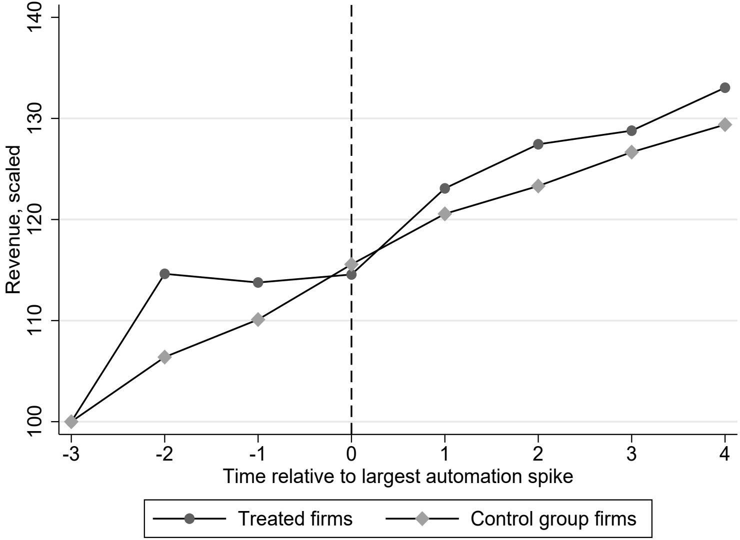
Employment for treated and control group firms



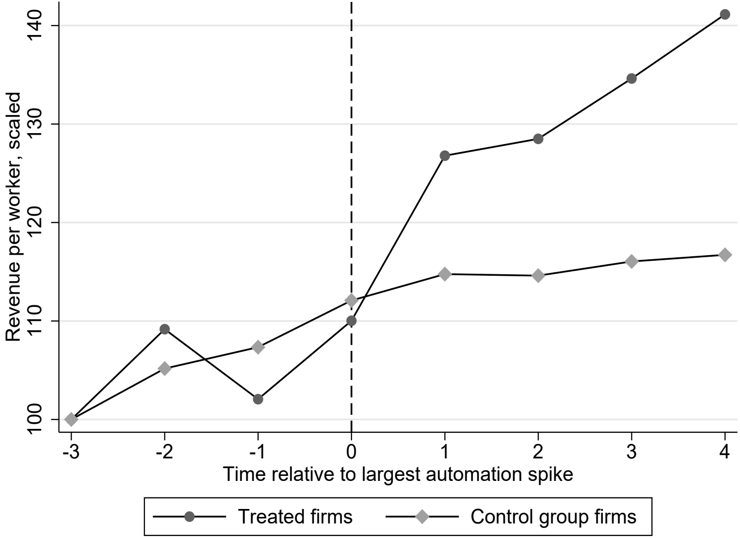
Mean daily wage for treated and control group firms



Total revenue for treated and control group firms



Revenue per worker for treated and control group firms



Agenda

Comparison to computerization

- Are **displacement effects specific to automation?**
- **Compare** worker-level impacts **to other technology**
- Use partially overlapping firm survey on **computer investments**
  - "All data-processing electronic equipment insofar as they can be freely programmed by the user, including all supporting appliances."
- Use **same event study DiD** design to study **computerization**

Summary statistics on overlapping sample

	Automation cost (€)		Computer investment (€)	
	level	*per worker*	*level*	*per worker*
p5	0	0	0	0
p10	0	0	0	0
p25	0	0	0	0
p50	16,747	297	5,554	99
p75	69,617	957	31,042	447
p90	241,274	2,175	112,889	1,126
p95	568,915	3,518	250,652	1,868
mean	**249,275**	**1,032**	**99,666**	**559**
mean excl. zeros	**346,396**	**1,434**	**155,619**	**873**
N firms $\times$ yrs	171,549			

Automation costs & computer investments by sector

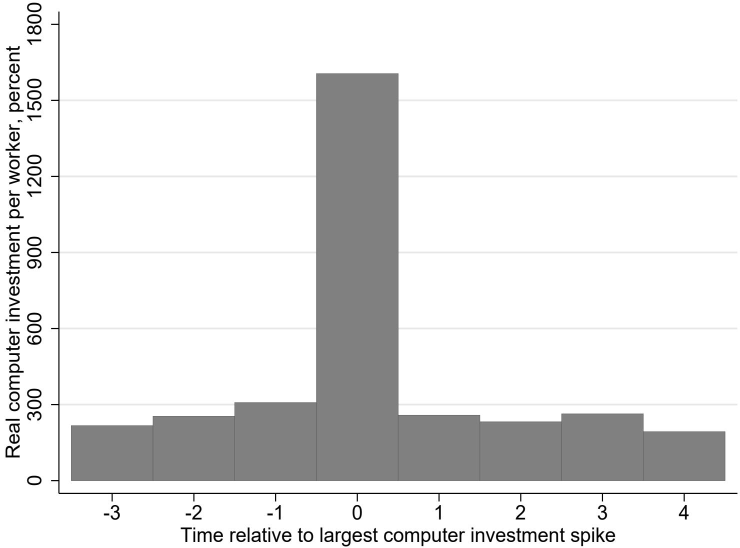
over time

Sector	Autom. cost per worker (€)	Comp. inv. per worker (€)	Autom. to comp.	*N Firms* $\times$ *yrs*
Manufacturing	998	369	2.7	40,773
Construction	497	215	2.3	18,319
Wholesale & retail trade	1,152	544	2.1	50,381
Transportation & storage	917	456	2.0	15,834
Accommodation & food serving	256	151	1.7	4,462
Information & communication	2,030	2,420	0.8	9,756
Prof'l, scientific, & techn'l act's	1,272	772	1.6	14,708
Admin & support act's	863	388	2.2	17,316

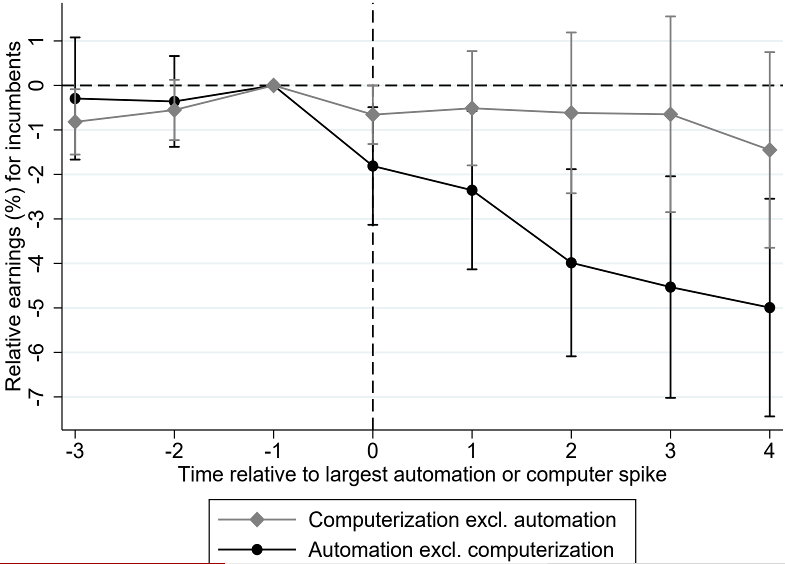
Spike frequencies, overlapping sample

	Percentage of firms with event type:	
Nr of events	Automation	Computerization
0	71.8	47.9
1	22.5	41.9
2	4.8	9.1
3	0.7	1.1
4	0.1	0.1

Computer investment event spikes, estimation sample



Automation versus computerization



Agenda

Conclusions

1. Automation leads to **displacement** for incumbent workers
   - Firm separation $\uparrow \rightarrow$ Non-employment $\uparrow \rightarrow$ **Annual earnings** $\downarrow$
   - **No wage scarring**, but earnings losses only partially offset by benefits
2. Affected workers more likely to **switch industries** and enter **early retirement**
3. Effects are **pervasive** across industries and worker types
4. Automation appears to be **more labor-displacing than computerization**

Appendices

Appendix: Data cleaning

Data cleaning

We remove the following observations:

- Workers enrolled in full-time studies earning either less than EUR 5K annually or EUR 10 daily on average across the year
- Workers with earnings above EUR 500K annually or EUR 2K daily on average across the year
- Later, we further exclude workers at firms that have:
  - Not a single spike in automation cost shares
  - No event window (7 yrs of consecutive data)
  - Other events in the event window (mergers, takeovers, splits, restructuring)
  - Large (>90%) annual employment changes in the event window or also outside the event window

Go Back

Estimation sample

- 36K unique firms have at least 3 yrs of automation cost data
- *Of those*, there are 10K unique firms that have at least one automation spike
- *Of those*, **the estimation sample** are 6K unique firms that have at least 7 yrs of consecutive data, i.e. have an event window
- Those 6K firms employ 1M unique incumbent workers annually on average, resulting in 8.4M worker-year observations in our estimations
- The estimation sample consists of 2K **treated firms** that have observations 3 yrs before and 4 yrs after their spike (that spike between 2003-2011) Go Back

Appendix: Matching details

CEM statistics

- Coarsened Exact Matching (CEM):
    1. In each of the three pre-treatment years, separate strata for each 5 percentiles of annual wage + separate bins for the 99th and 99.5th percentiles
    2. One year prior to treatment, matched workers must be observed in the same calendar year and work in the same sector
- 30,247 strata
- 98% of treated incumbents are matched; and 93% of control group incumbents are assigned a non-zero weight

Go Back

Appendix: Further summary statistics

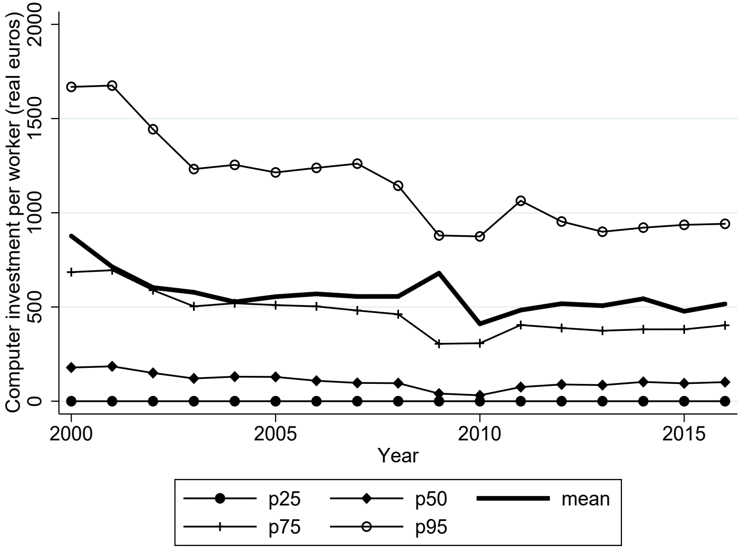
Automation costs by firm size

Go Back

Firm size class	Cost per worker (€) Mean	SD	Cost share (%) Mean	SD	Nr of obs *Firm* × *yr*
1-19 employees	1,114	18,317	0.40	1.27	51,128
20-49 employees	803	4,426	0.42	1.23	86,036
50-99 employees	817	3,142	0.42	1.23	45,797
100-199 employees	930	2,452	0.44	0.92	29,073
200-499 employees	1,186	3,905	0.52	1.17	17,694
≥500 employees	1,656	6,884	0.74	1.53	10,609

Computer investment per worker over time

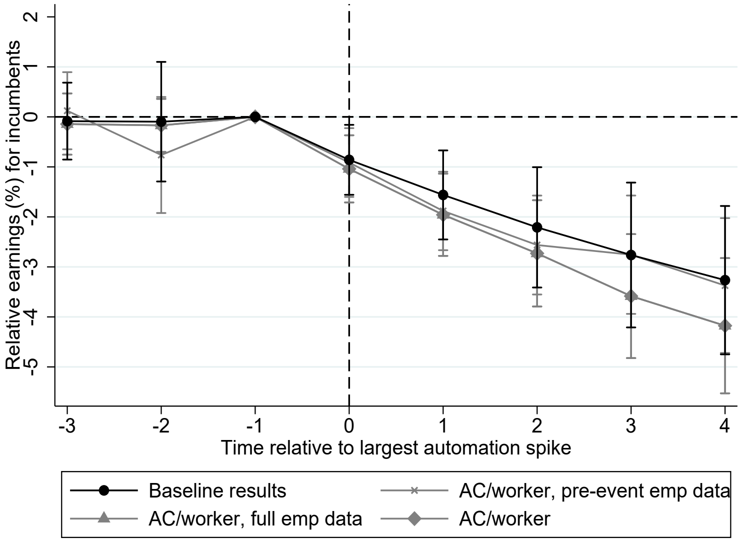
Go Back



Appendix: Further robustness checks

Robustness to spike definition: Annual wage (%)

Go Back



Robustness to model spec.: Annual wage (%)

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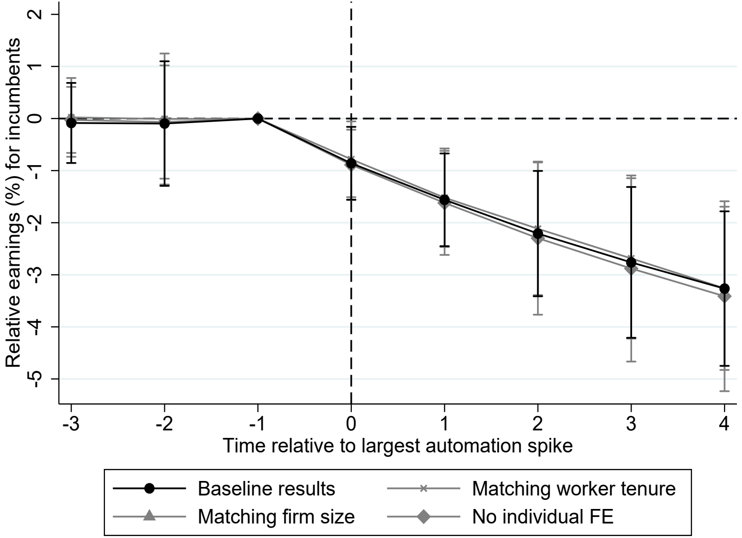

Randomization test: Firm separation

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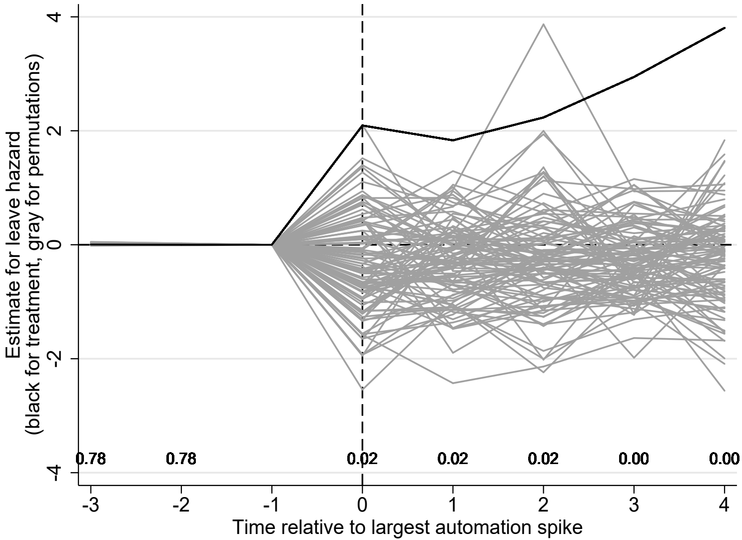

Robustness to other events: Firm separation

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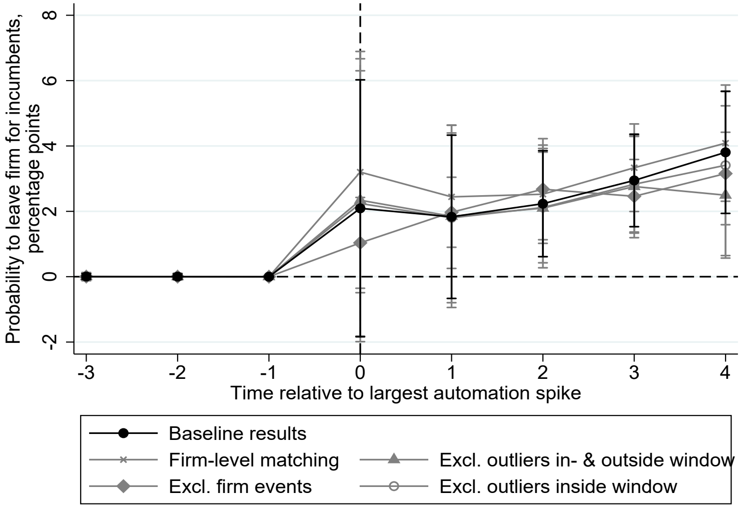

Robustness to spike definition: Firm separation

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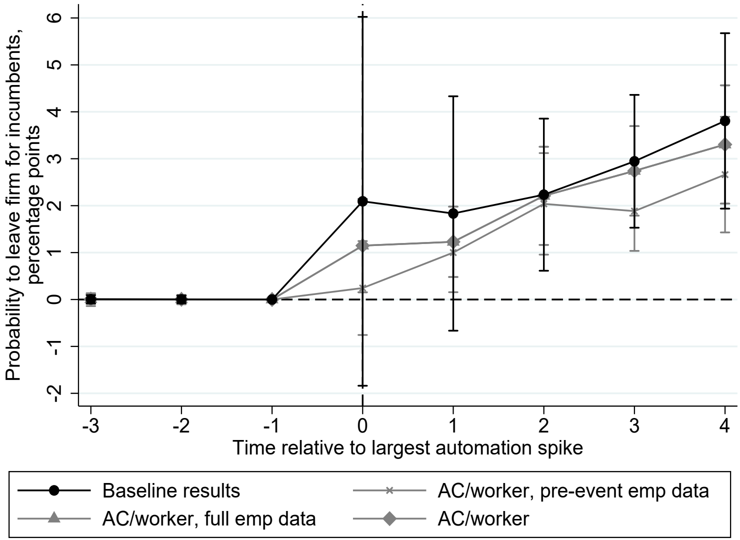

Robustness to model spec.: Firm separation

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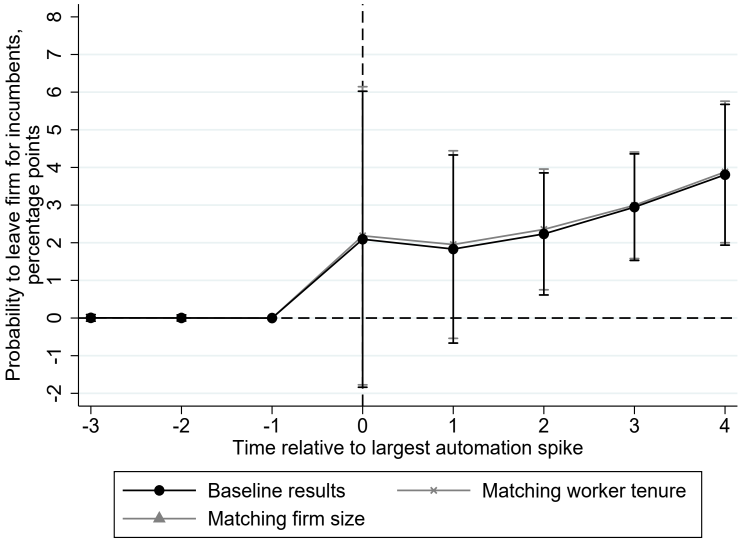

Non-employment estimates, randomization test

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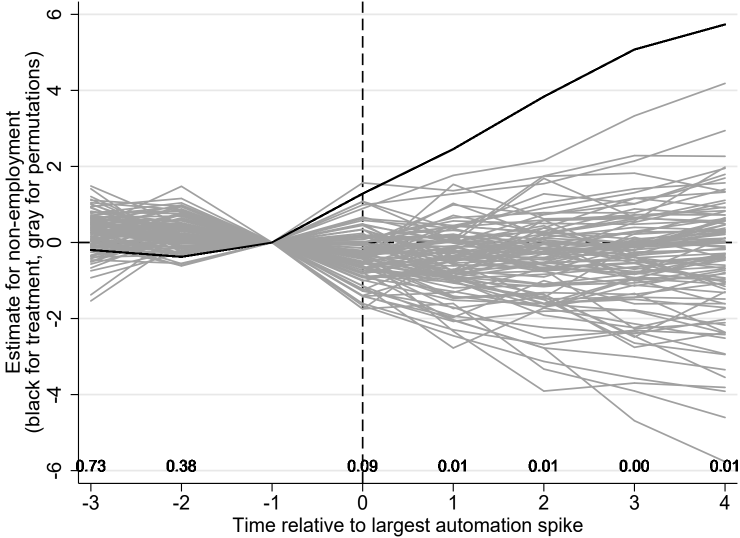

Daily wage estimates, randomization test

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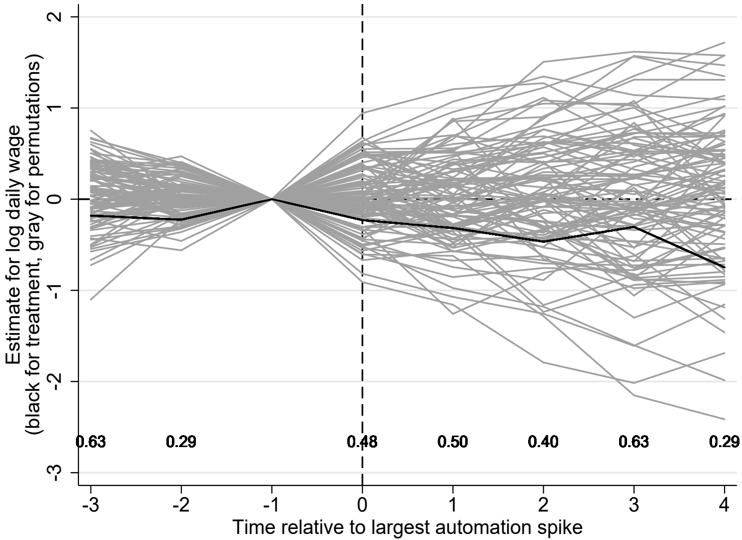
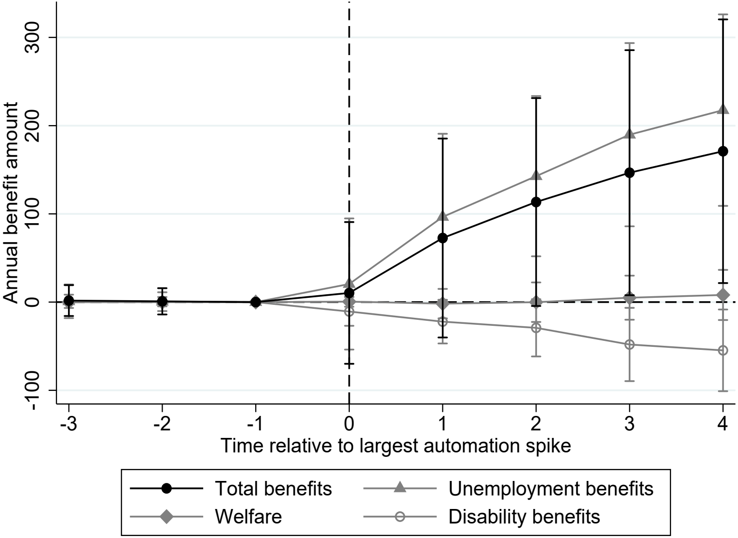


Appendix: Further estimates

Annual benefit income split

Go Back



Heterogeneity in average annual wage impact

Go Back

(1) Age		(3) Gender	
Age <30 (ref)	-1.84	Male (ref)	-1.52***
	(3.19)		(0.57)
Deviations from reference group for:		*Deviations from reference group for:*	
Age 30-39	-0.24	Female	-1.39
	(3.73)		(0.97)
Age 40-49	0.42	(4) Sector	
	(3.60)	Manufacturing (ref)	-1.98**
Age 50+	-1.20		(0.99)
	(3.94)	*Deviations from reference group for:*	
(2) Firm size		Construction	1.05
500+ employees (ref)	-1.53		(1.73)
	(1.35)	Wholesale & retail trade	-2.23
Deviations from reference group for:			(1.51)
200-499 employees	1.21	Transportation & storage	0.71
	(1.77)		(1.79)
100-199 employees	-2.19	Accommodation & food serving	4.57**
	(1.77)		(2.32)
50-99 employees	0.17	Information and communication	-0.25
	(1.57)		(1.76)
20-49 employees	-2.18	Prof'l, scientific, & techn'l act's	-0.24
	(1.46)		(1.80)
1-19 employees	-2.06	Administrative & support act's	1.55
	(1.52)		(2.01)

Heterogeneity in average annual wage impact

Go Back

(1) Overall age-specific wage quartile		(2) Within-firm age-specific wage quartile	
Bottom quartile (ref)	-2.26*	Bottom quartile (ref)	-1.06
	(1.20)		(1.26)
Deviations from reference group for:		*Deviations from reference group for:*	
Second quartile	0.17	Second quartile	-1.37
	(1.10)		(1.12)
Third quartile	0.48	Third quartile	-0.75
	(1.39)		(1.31)
Top quartile	0.09	Top quartile	-1.62
	(1.65)		(1.56)

Annual earnings for incumbents vs. recent hires

Go Back