

# 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

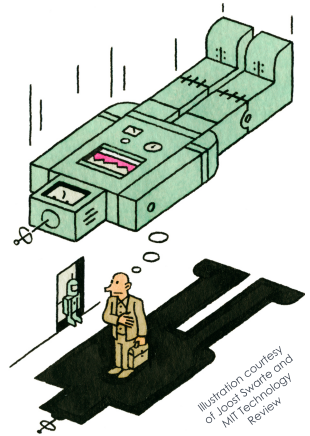


Illustration courtesy  
of Joost Swarte and  
MIT Technology  
Review

# Does automation lead to labor displacement?

- Advancing digital technologies like robotics and AI are **increasing opportunities for automation of work**
- **Task-based frameworks: potential displacement effects** as tech progress increases the range of tasks that can be automated.  
Autor-Levy-Murnane '03, Acemoglu-Autor '11, Acemoglu-Restrepo '16, '18a,b,d, Benzell-Kotlikoff-LaGarda-Sachs '18, Susskind '17
- Literature on firm closures and other **mass lay-off events: significant harm from displacement** (employment, wages, health ↓)  
Abbring et al '02, Couch-Placzek '10, Davis-VonWachter '11, Deelen-deGraafZijl-vandenBerge '18, Jacobson-Lalonde-Sullivan '93

# Does automation lead to labor displacement?

## Empirical evidence:

- **Aggregate impacts** (industry, regional, or national level):
  - *Innovation & technological progress more broadly*: Autor-Salomons '18, Gregory-Salomons-Zierahn '18, Karabarbounis-Neiman '14
  - *Automation by robotics*: Acemoglu-Restrepo '18c, Dauth-Findeisen-Suedekum-Wossner '18, Graetz-Michaels '18
- **Firm- and worker-level impacts**
  - *Innovation & technological progress more broadly*: Cortés '16, Cortés-Salvatori '16, Harrigan-Reshef-Toubal '16, Harrison-Jaumandreu-Mairesse-Peters '14
  - *Automation*: Dinlersoz-Wolf '18

# This paper

Study the **impacts of automation on individual worker outcomes**

- Wage earnings, firm separation, and non-employment duration
- Usage of various benefits systems
- Heterogeneity of impacts across different worker types

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Study the **impacts of automation on individual worker outcomes**

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## **Contributions:**

- 1 Consider worker-level impacts of automation
- 2 Directly measure firm-level automation expenditures
- 3 All private non-financial sectors of the economy
- 4 Exploit timing of automation cost spikes at the firm level for empirical identification

## Preview of findings

- Automation leads to **displacement**: workers experience a 10 to 20% **higher firm separation rate**.
- Days in **non-employment increases** with 9% after 5 years for incumbent workers, but **little scarring in daily wages** on average.
- Total wage **earnings loss** of 8% of one year's earnings after 5 years, only partially compensated by benefit systems.
- Earnings losses are
  - larger for workers who have longer firm tenure, are older, and are employed in smaller firms
  - found in most industries
  - small compared the effects of mass lay-offs / firm closures

# Agenda

- 1 Data and summary statistics
  - Data sources and coverage
  - Summary statistics
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  - Defining automation spikes
  - An event study DiD design
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# Data

Data source: Statistics Netherlands

- Administrative matched employer-employee records
- Linked to firm survey which includes a **direct question on automation costs**
- Years **2000-2016**
- **36,085 firms** with at least three years of data on automation costs
- **Estimation sample = 2,753 firms** and **1,638,434 workers** that we can follow for at least 8 years.

▶ Data cleaning

# Automation costs

- Annual survey of **non-financial private-sector firms**; covers all large firms (>50 employees), and samples smaller firms.
- Defined as costs of **third-party automation services**
  - Also includes non-activated purchases of custom software and costs of new software releases; does not include software licensing costs
  - Not restricted to manufacturing; could include self-service check-out, warehouse and storage systems, automated customer service, robot integrators ...
- Automation costs are **not correlated with computer investment**.
- We calculate **automation cost shares** by scaling relative to time-averaged total costs to avoid conflating automation cost increases with scale effects.

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## Automation cost distribution

	<b>All observations</b>		<b>Automation costs &gt;0</b>	
	<i>Cost level</i>	<i>Cost share</i>	<i>Cost level</i>	<i>Cost share</i>
p5	0	0.00%	2,026	0.03%
p10	0	0.00%	3,663	0.06%
p25	0	0.00%	9,775	0.14%
median	10,988	0.15%	27,912	0.31%
p75	49,446	0.47%	87,115	0.67%
p90	179,641	1.05%	283,703	1.36%
p95	422,000	1.69%	658,695	2.11%
<b>mean</b>	<b>196,351</b>	<b>0.45%</b>	<b>284,692</b>	<b>0.65%</b>
% of N with 0 costs	31%	31%	0%	0%
N firms × years	241,292	241,292	166,418	166,418

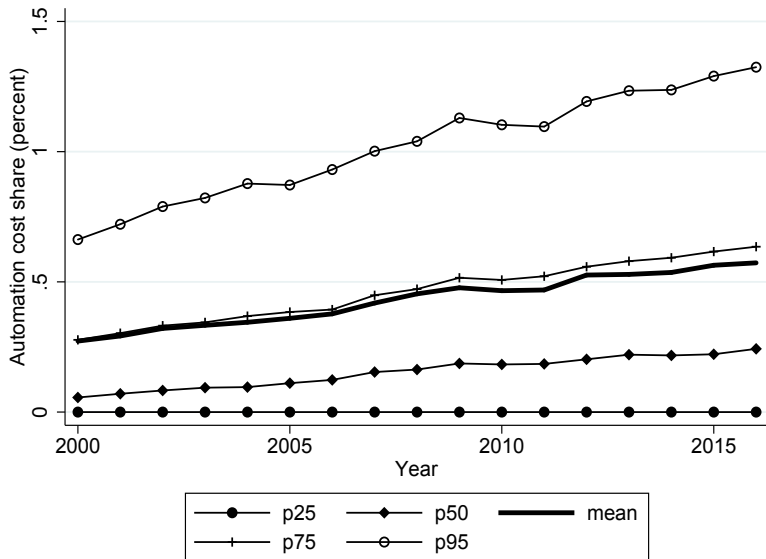
# Automation cost by sector

Sector	Cost level	Cost share		Nr of obs
	<i>Mean</i>	<i>Mean</i>	<i>Std dev</i>	<i>Firms × yrs</i>
Manufacturing	395,310	0.36%	0.63%	45,308
Construction	72,400	0.20%	0.36%	28,927
Wholesale & retail trade	107,600	0.33%	7.51%	76,283
Transportation & storage	255,270	0.40%	0.98%	21,779
Accommodation & food serving	53,550	0.30%	0.49%	6,355
Information & communication	427,080	0.87%	3.10%	16,804
Prof'l, scientific, & technical act's	142,720	1.05%	1.80%	22,826
Administrative & support act's	123,030	0.50%	1.24%	23,010

# Automation cost by firm size

Firm size class	Cost level	Cost share		Nr of obs	
	<i>Mean</i>	<i>Mean</i>	<i>Std dev</i>	<i>Firms</i>	<i>Firms × yrs</i>
0-9 employees	22,670	0.35%	1.05%	9,241	48,869
10-19 employees	24,890	0.47%	9.34%	8,036	49,112
20-49 employees	48,750	0.44%	1.61%	9,771	68,872
50-99 employees	105,130	0.44%	1.04%	4,464	34,758
100-199 employees	265,650	0.49%	1.14%	2,344	19,825
200-499 employees	712,990	0.59%	1.37%	1,446	12,620
≥500 employees	3,285,220	0.70%	1.78%	783	7,236

# Automation cost share distribution over time





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# Automation cost spikes vs run-of-the-mill automation

- We hypothesize that **spikes in automation cost shares** at the firm level **signal changes in work processes related to automation**
- We define a spike as a year in which the automation cost share is  $\geq$  **3 times the average firm-level cost share**
- This identifies events that are large for the firm
- We now
  - define automation spikes and show that they exist;
  - discuss why such spikes occur;
  - outline our empirical framework for identification

## Defining automation spikes

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

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

where  $\mathbb{1}\{\dots\}$  denotes the indicator function.

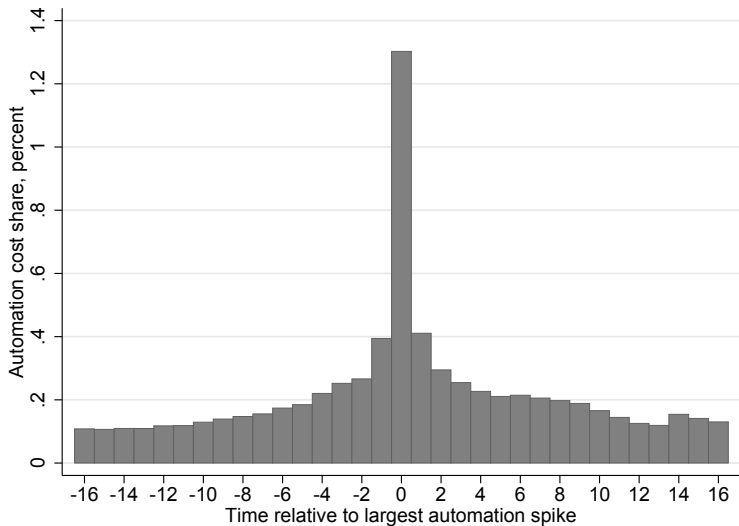
- **Firm-specific measure:** identifies automation events that are large for the firm, independent of firm's initial automation expenditure level – no mechanical correlation with firm characteristics

# Automation spike frequency at the firm level

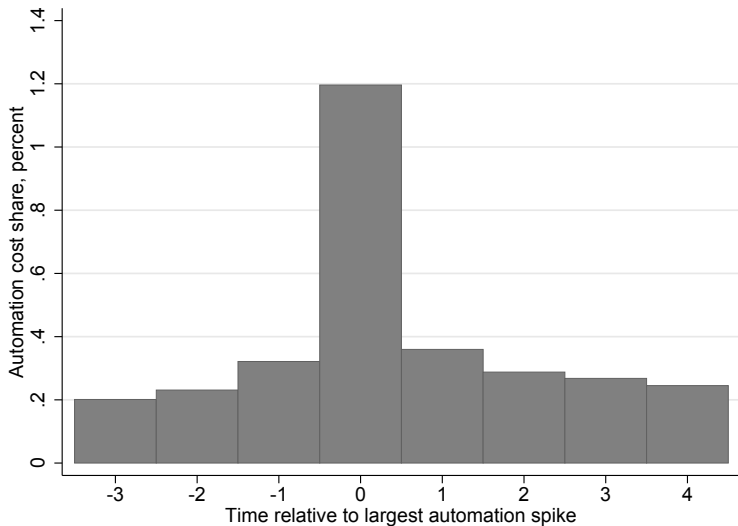
<b>Spike frequency over 2000-2016</b>	<b>N firms</b>	<b>% of N Firms</b>
0	23,807	66.0%
1	9,572	26.5%
2	2,297	6.4%
3	359	1.0%
4	46	0.1%

Around 8 percent of firms spikes in any one year

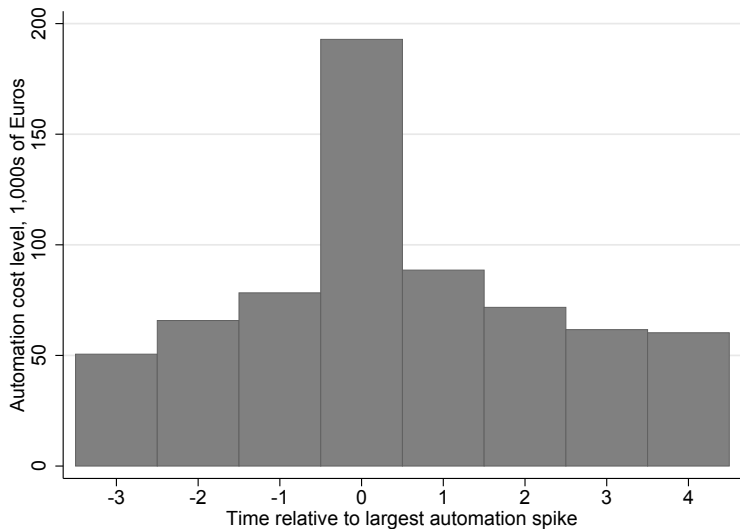
# Automation cost share spikes exist



# Automation cost share spikes: estimation sample



# Automation cost level during spikes: estimation sample





# Why do firms experience automation spikes?

- Spikes → **investment is lumpy**: significant share of automation investment occurs in episodes of disproportionately large quantities
- Spikes arise when the investment is **irreversible** and there are **indivisibilities**
  - Under uncertainty, irreversibility creates an 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.

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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
- We assume the **timing of automation cost spikes** is random (conditional on controls) from the perspective of incumbent workers (cf. mass lay-off literature)
- Treatment is based on **differences in automation spike timing** across firms
  - Related event study approaches: Borusyak-Jaravel '18;  
Duggan-Garthwaite-Goyal '16; Fadlon-Nielsen '17; Miller '17;  
Lafortune-Rothstein-Schanzenbach '18
- Uncertainty & indivisibility → small  $\Delta$  in payoff to automating can generate substantial  $\Delta$  in the timing of investment (Bessen '99)

# Defining treatment and controls

- Workers at a firm are **treated** in year  $\tau$  if that firm undergoes an automation spike in year  $\tau$
- Workers who work at firms who spike at  $\tau + k$  or later are used as **controls** for the years  $\tau - k - 1$ , where we choose  $k = 5$
- **Match** controls and treated on their pre-treatment income, sector, and calendar year to create groups that are more comparable (using CEM, see Blackwell-lacus-King-Porro '09, lacus-King-Porro '12) [▶ Matching details](#)
- Distinguish **incumbent workers** and **recent hires**: incumbents have been at the firm for at least three years prior to the automation event.

# Empirical model

Dynamic DiD model exploiting timing of automation spikes:

$$y_{ijt} = \alpha + \beta \text{treat}_i + \sum_{t \neq -1; t = -3}^4 \gamma_t \times l_t + \sum_{t \neq -1; t = -3}^4 \delta_t \times l_t \times \text{treat}_i + \lambda X_{ijt} + \varepsilon_{ijt},$$

- $i$  indexes workers,  $j$  firms and  $t$  time, measured relative to the automation spike in year  $\tau$ , i.e.  $t \equiv \text{year} - \tau$ .
- $\text{treat}_i$  is a treatment indicator = 1 if worker  $i$  is employed at a firm experiencing an automation spike at  $t = 0$
- $l_t$  indicate time relative to the spike year, with  $t \in \{-3, 4\}$ , and  $t = -1$  as reference category.

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- Parameters of interest are  $\delta_t$  : period  $t$  treatment effect relative to pre-treatment period  $t = -1$
- $X_{ijt}$  are controls: worker age, age<sup>2</sup>, gender, nationality; sector and size class of the spiking firm; year fixed effects.
- Identification requires parallel trends

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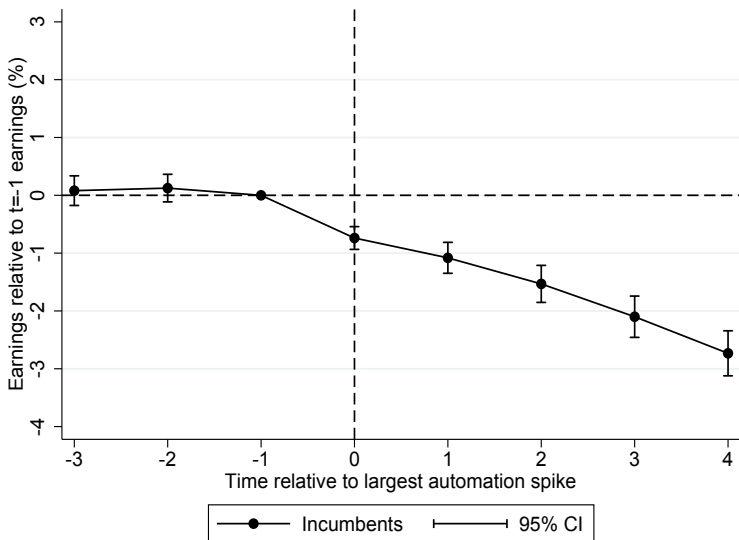
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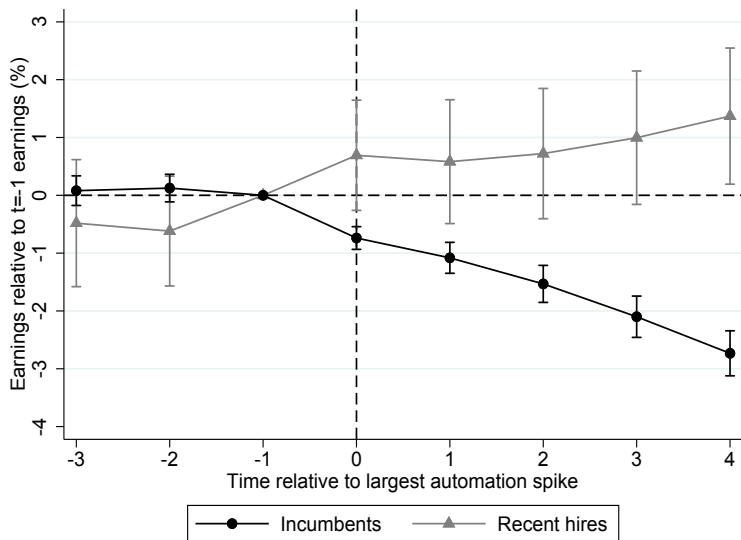


# Annual wage earnings, relative to $t=-1$ earnings

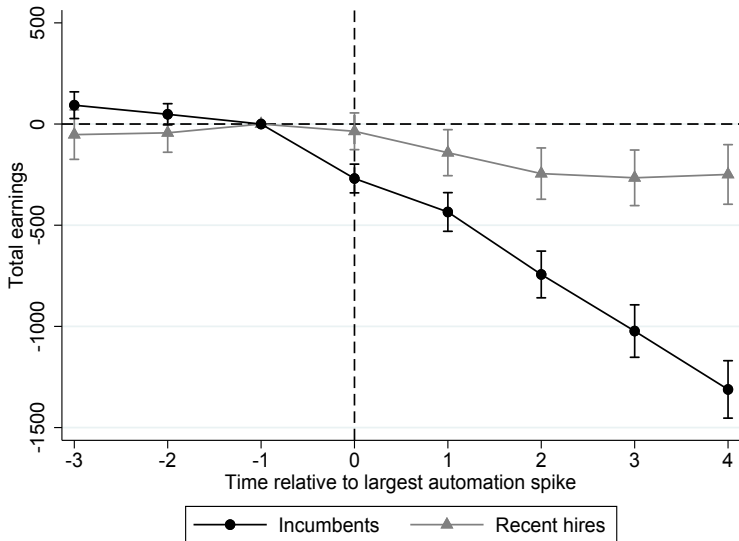
▶ effect scaling



# Annual wage earnings, relative to $t=-1$ earnings



# Annual wage earnings levels

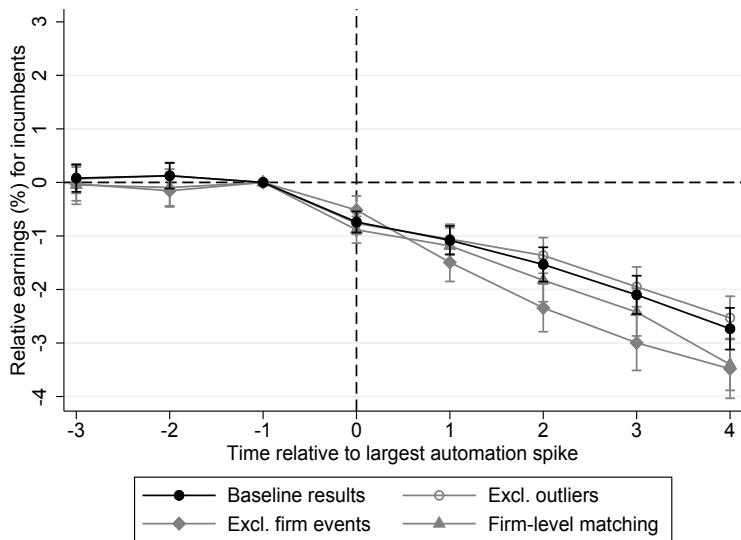


# Robustness checks

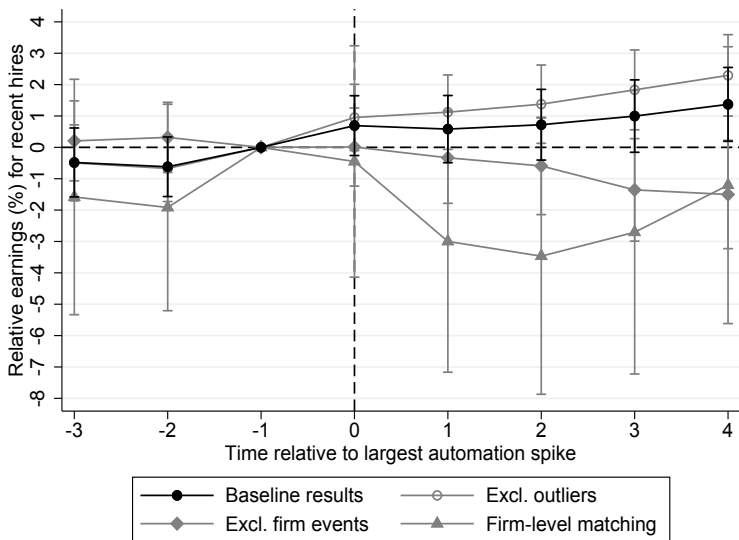
Results may be driven by **other firm-level events** – robustness checks:

- Eliminate firms that experience other observable events in the estimation window (mergers, takeovers, splits, restructuring, births).
- Match treated & control group workers to be employed in firms with similar pre-treatment employment trends.
- Remove outliers (firms with large annual employment changes at any one point in the estimation window).

# Annual wage earnings: robustness checks for incumbents



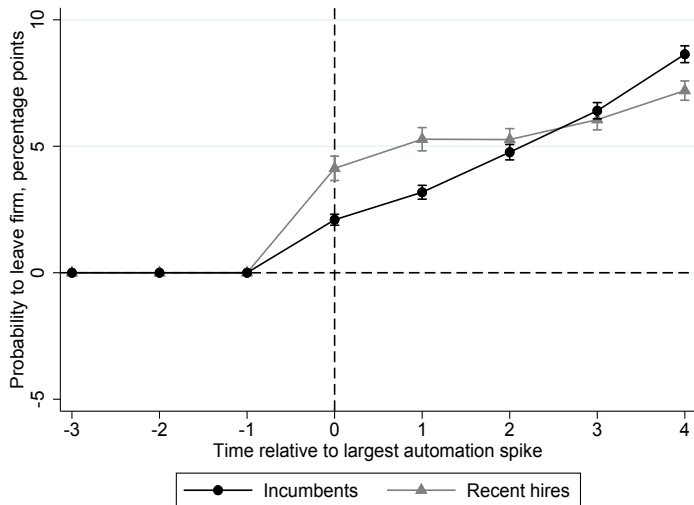
# Annual wage earnings: robustness checks for recent hires



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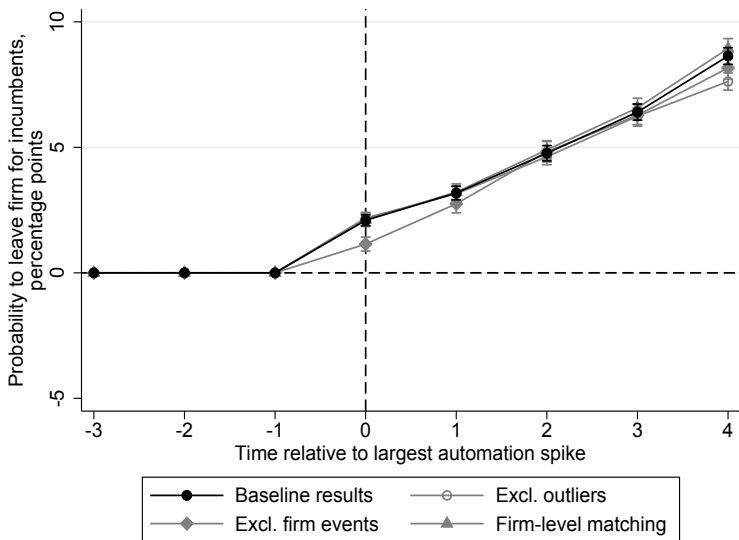
# Probability of firm separation



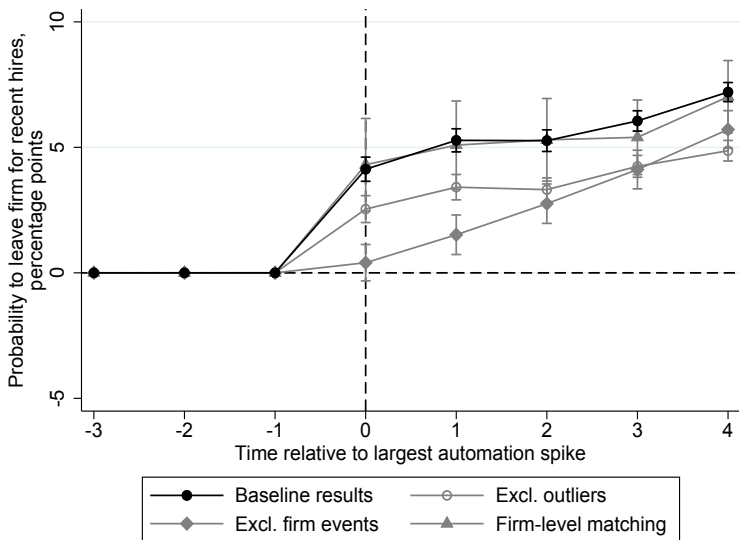
Rel. to CG 1-yr (5-yr): 16% (24%) ↑ for incumbents, & 13% (10%) ↑ for recent hires



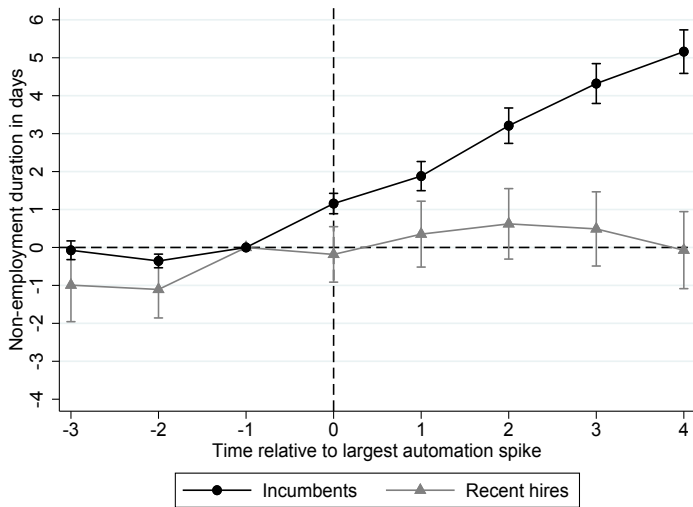
# Firm separation: robustness checks for incumbents



# Firm separation: robustness checks for recent hires

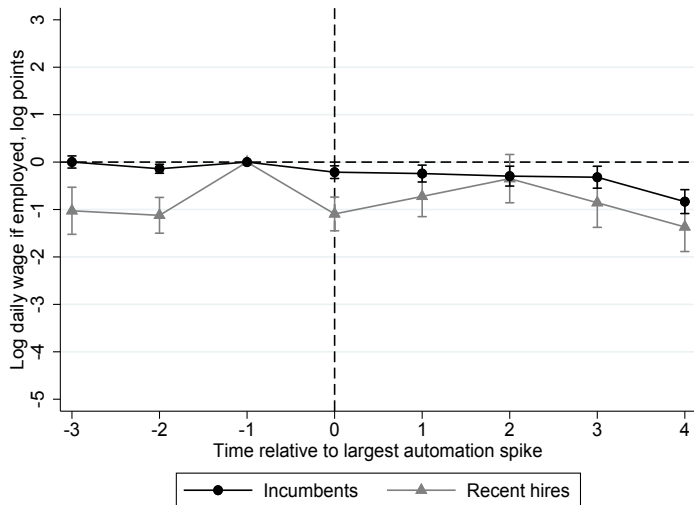


# Non-employment duration (in days)



Rel. to CG 1-yr (5-yr): 5.4% (9.1%) ↑ for incumbents, & 0% (0%) ↑ for recent hires

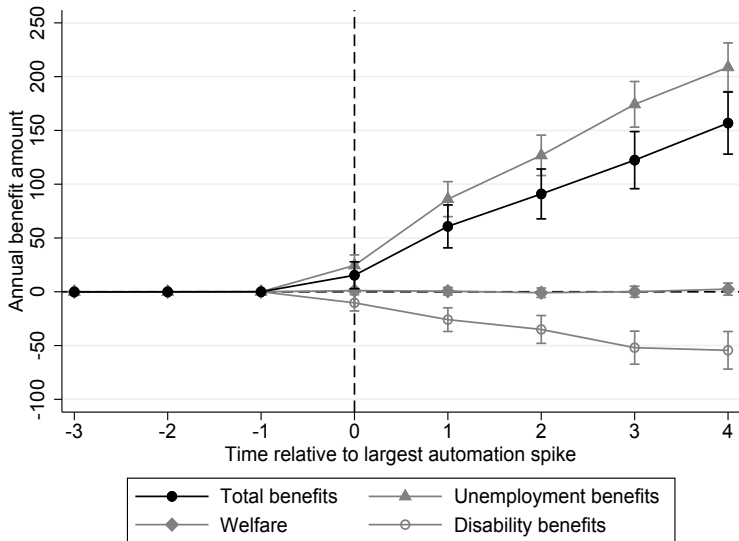
# Log daily wage conditional on employment



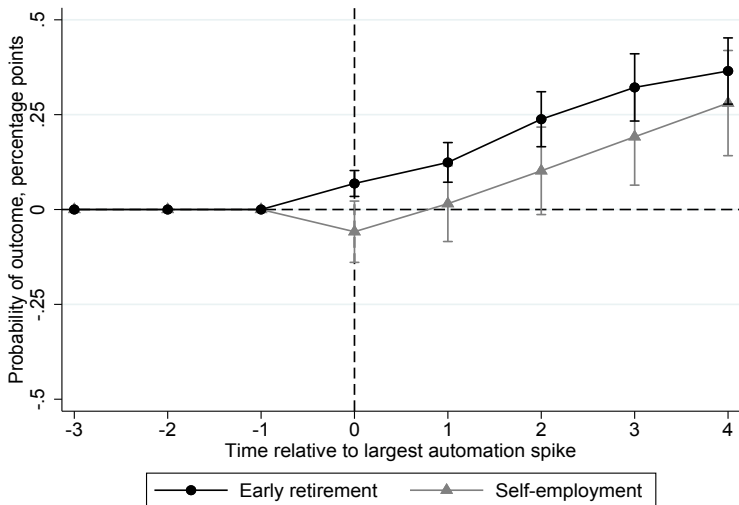
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# Benefit income



# Incidences of self-employment and early retirement



Rel. to CG 5-yr: 5.8% ↑ for self-empl, & 24% ↑ for early retirement.

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## Estimating equation

Estimate the **average annual effect over the post-treatment period**:

$$y_{ijt} = \alpha + \beta \text{treat}_i + \gamma \text{post}_{it} + \delta_0 \times \text{treat}_i \times \text{post}_{it} \\ + \sum_k [\delta_k \times \text{treat}_i \times \text{post}_{it} \times z_{ki}] + \lambda X_{ijt} + \varepsilon_{ijt}$$

- $\text{post}_{it}$  is a dummy variable indicating the post-treatment period (i.e.  $t \geq 0$ ).
- $z_{ki}$  is a dimension of worker heterogeneity, containing  $k + 1$  categories.
- $X_{ijt}$  includes controls, as well as  $z_{ki}$ ,  $z_{ki} \times \text{treat}_i$ , and  $z_{ki} \times \text{post}_{it}$ .
- $\delta_0$  gives the estimated treatment effect for the reference group, and  $\delta_k$  the deviation from that effect for category  $k$  of worker characteristic  $z_i$ .

# Effect heterogeneity by age

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Age <30 (ref)	-0.73 (0.56)	5.79*** (0.37)	0.66 (0.53)	-0.64** (0.23)	-0.00 (0.01)
<i>Deviations from reference group for:</i>					
Age 30-39	-1.19 (0.62)	-1.58*** (0.44)	2.23*** (0.63)	-0.17 (0.27)	0.01 (0.01)
Age 40-49	-0.83 (0.61)	-0.46 (0.43)	2.60*** (0.62)	0.60* (0.27)	0.01 (0.01)
Age 50+	-1.56* (0.64)	-1.02* (0.44)	4.33*** (0.72)	0.65* (0.29)	0.83*** (0.11)

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	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Age <30 (ref)	2.26* (0.92)	3.08*** (0.30)	0.63 (0.71)	1.05*** (0.31)	0.01 (0.01)
<i>Deviations from reference group for:</i>					
Age 30-39	-2.24 (1.29)	1.96*** (0.44)	1.03 (1.02)	-1.77*** (0.44)	-0.02 (0.02)
Age 40-49	1.12 (1.48)	5.19*** (0.50)	-0.82 (1.16)	-1.12* (0.49)	-0.06 (0.03)
Age 50+	-3.13 (1.91)	6.74*** (0.64)	1.11 (1.52)	-3.37*** (0.71)	0.49** (0.18)

# Effect heterogeneity by age

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Age <30 (ref)	2.26*	3.08***	0.63	1.05***	0.01
	(0.92)	(0.30)	(0.71)	(0.31)	(0.01)
<i>Deviations from reference group for:</i>					
Age 30-39	-2.24	1.96***	1.03	-1.77***	-0.02
	(1.29)	(0.44)	(1.02)	(0.44)	(0.02)
Age 40-49	1.12	5.19***	-0.82	-1.12*	-0.06
	(1.48)	(0.50)	(1.16)	(0.49)	(0.03)
Age 50+	-3.13	6.74***	1.11	-3.37***	0.49**
	(1.91)	(0.64)	(1.52)	(0.71)	(0.18)

# Effect heterogeneity by age

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<i>Deviations from reference group for:</i>					
Age 30-39	-2.24 (1.29)	1.96*** (0.44)	1.03 (1.02)	-1.77*** (0.44)	-0.02 (0.02)
Age 40-49	1.12 (1.48)	5.19*** (0.50)	-0.82 (1.16)	-1.12* (0.49)	-0.06 (0.03)
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Age 30-39	-2.24 (1.29)	1.96*** (0.44)	1.03 (1.02)	-1.77*** (0.44)	-0.02 (0.02)
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## Effect heterogeneity by firm size

▶ by firm sector

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
≥500 employees (ref)	-0.01 (0.28)	6.81*** (0.22)	3.38*** (0.33)	0.71*** (0.14)	0.41*** (0.04)
<i>Deviations from reference group for:</i>					
200-499 employees	-2.14*** (0.45)	-3.07*** (0.37)	-0.70 (0.60)	-0.76** (0.24)	-0.43*** (0.08)
100-199 employees	-2.20*** (0.49)	-2.52*** (0.41)	-0.72 (0.64)	-1.80*** (0.26)	-0.34*** (0.08)
50-99 employees	-2.23*** (0.50)	-2.88*** (0.41)	-1.11 (0.64)	-1.59*** (0.25)	-0.45*** (0.08)
20-49 employees	-4.22*** (0.46)	-3.26*** (0.37)	0.93 (0.59)	-2.31*** (0.23)	-0.18* (0.08)
<10-19 employees	-4.55*** (0.75)	-2.98*** (0.61)	2.72** (1.04)	-3.46*** (0.42)	-0.06 (0.13)

## Effect heterogeneity by firm size

▶ by firm sector

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<10-19 employees	-4.55*** (0.75)	-2.98*** (0.61)	2.72** (1.04)	-3.46*** (0.42)	-0.06 (0.13)

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<10-19 employees	-4.55*** (0.75)	-2.98*** (0.61)	2.72** (1.04)	-3.46*** (0.42)	-0.06 (0.13)

## Effect heterogeneity by firm size

▶ by firm sector

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
≥500 employees (ref)	3.50*** (0.74)	6.48*** (0.22)	-1.07 (0.57)	0.08 (0.25)	0.05 (0.03)
<i>Deviations from reference group for:</i>					
200-499 employees	-3.58* (1.67)	-9.88*** (0.68)	4.59** (1.40)	1.97*** (0.59)	-0.05 (0.07)
100-199 employees	-8.97*** (1.72)	-4.88*** (0.68)	8.57*** (1.44)	-1.38* (0.62)	0.09 (0.09)
50-99 employees	-5.97*** (1.61)	-3.69*** (0.73)	7.29*** (1.44)	-0.65 (0.57)	-0.09 (0.07)
20-49 employees	-6.46*** (1.44)	-1.60* (0.67)	3.95** (1.33)	-1.15* (0.52)	-0.09 (0.06)
<10-19 employees	-11.10*** (2.31)	-3.85** (1.25)	5.93* (2.38)	-2.87** (0.93)	-0.06 (0.09)

## Effect heterogeneity by firm size

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50-99 employees	-5.97*** (1.61)	-3.69*** (0.73)	7.29*** (1.44)	-0.65 (0.57)	-0.09 (0.07)
20-49 employees	-6.46*** (1.44)	-1.60* (0.67)	3.95** (1.33)	-1.15* (0.52)	-0.09 (0.06)
<10-19 employees	-11.10*** (2.31)	-3.85** (1.25)	5.93* (2.38)	-2.87** (0.93)	-0.06 (0.09)

# Effect heterogeneity by age-specific *within-firm* wage quartile

▶ overall wage quartile

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Bottom quartile (ref)	-1.86*** (0.40)	5.33*** (0.27)	4.31*** (0.44)	-0.01 (0.18)	0.24*** (0.06)
<i>Deviations from reference group for:</i>					
Second quartile	0.14 (0.50)	-0.99** (0.37)	-1.49* (0.60)	-0.53* (0.23)	0.05 (0.08)
Third quartile	0.17 (0.48)	-0.51 (0.37)	-1.14 (0.59)	-0.44 (0.23)	0.09 (0.08)
Top quartile	0.40 (0.50)	0.11 (0.38)	-2.13*** (0.60)	-0.70** (0.25)	-0.11 (0.08)



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# Effect heterogeneity by age-specific *within-firm* wage quartile

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Bottom quartile (ref)	3.95** (1.33)	6.54*** (0.36)	-1.82* (0.85)	-0.50 (0.43)	0.04 (0.05)
<i>Deviations from reference group for:</i>					
Second quartile	-4.27* (1.70)	-0.00 (0.52)	3.15* (1.23)	-0.05 (0.56)	-0.03 (0.07)
Third quartile	-3.40* (1.64)	-0.75 (0.52)	3.87** (1.22)	0.47 (0.54)	-0.03 (0.06)
Top quartile	-1.70 (1.65)	0.52 (0.53)	2.78* (1.21)	1.25* (0.55)	0.10 (0.08)

# Effect heterogeneity by age-specific *within-firm* wage quartile

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Bottom quartile (ref)	3.95** (1.33)	6.54*** (0.36)	-1.82* (0.85)	-0.50 (0.43)	0.04 (0.05)
<i>Deviations from reference group for:</i>					
Second quartile	-4.27* (1.70)	-0.00 (0.52)	3.15* (1.23)	-0.05 (0.56)	-0.03 (0.07)
Third quartile	-3.40* (1.64)	-0.75 (0.52)	3.87** (1.22)	0.47 (0.54)	-0.03 (0.06)
Top quartile	-1.70 (1.65)	0.52 (0.53)	2.78* (1.21)	1.25* (0.55)	0.10 (0.08)

# Effect heterogeneity by gender

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Male (ref)	-1.69*** (0.17)	4.92*** (0.15)	3.36*** (0.23)	-0.37*** (0.08)	0.32*** (0.03)
<i>Deviations from reference group for:</i>					
Female	0.11 (0.37)	-0.02 (0.29)	-0.56 (0.45)	0.12 (0.20)	-0.27*** (0.05)
Panel B. Recent hires					
Male (ref)	0.94 (0.66)	5.76*** (0.24)	1.81*** (0.54)	-0.03 (0.21)	0.10** (0.03)
<i>Deviations from reference group for:</i>					
Female	0.07 (1.11)	-0.64 (0.38)	-1.57 (0.87)	-0.52 (0.39)	-0.11* (0.05)

# Effect heterogeneity by gender

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Male (ref)	-1.69*** (0.17)	4.92*** (0.15)	3.36*** (0.23)	-0.37*** (0.08)	0.32*** (0.03)
<i>Deviations from reference group for:</i>					
Female	0.11 (0.37)	-0.02 (0.29)	-0.56 (0.45)	0.12 (0.20)	-0.27*** (0.05)
Panel B. Recent hires					
Male (ref)	0.94 (0.66)	5.76*** (0.24)	1.81*** (0.54)	-0.03 (0.21)	0.10** (0.03)
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Female	0.07 (1.11)	-0.64 (0.38)	-1.57 (0.87)	-0.52 (0.39)	-0.11* (0.05)

# Agenda

- 1 Data and summary statistics
  - Data sources and coverage
  - Summary statistics
- 2 Empirical approach
  - Defining automation spikes
  - An event study DiD design
- 3 Results
  - Impacts on annual wage income
  - Impacts on firm separation, non-employment, and wages
  - Impacts on benefits, early retirement, and self-employment
  - Heterogeneity in worker impacts
- 4 Impact comparison with mass lay-offs
- 5 Conclusions

# Comparison to mass lay-offs

	<b>Mass lay-offs</b>	<b>Automation</b>
<hr/> Annual displacement incidence <hr/>		
A. Workers employed at firms with event	12.5%	9.0%
B. Workers separating given event	40%	8.6%
C. Workers affected (=A×B)	5%	0.8%
<hr/> Earnings loss given displacement <hr/>		
D. Annual wage loss, year 5	19%	17%
<hr/> Wage scarring given displacement <hr/>		
E. Hourly wage loss, year 5	6%	< 1%

*Sources for mass lay-off effects:* C = Abbring et al '02; D = Couch & Placzek '10, Jacobson et al '93; E = Deelen et al '18, Mooi-Reci & Ganzeboom '15.

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## Findings (so far)

- 1 Automation leads to worker displacement: rise in firm separation
- 2 Annual wage losses driven by non-employment, only partially compensated by increased benefit receipts
- 3 Highest losses for workers who have longer firm tenure, are older, and are employed in smaller firms
- 4 Effects pervasive across sectors
- 5 Displacement low compared to mass lay-offs

### Next steps

- Estimate impacts for new hires (i.e. workers hired post-treatment)
- Compare automation with investments in ICT
- Examine changes in worker-firm matching following separation
- Further robustness checks (exploiting spike size, net income effects, ...)

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# Data cleaning

We remove the following observations:

- Workers with earnings above EUR 500,000 annually or EUR 2,000 daily on average across the year
- Workers enrolled in full-time studies earning either less than 5,000 Euros annually or 10 Euros daily on average across the year
- Firm-year observations with more than 90% annual employment change

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## CEM statistics

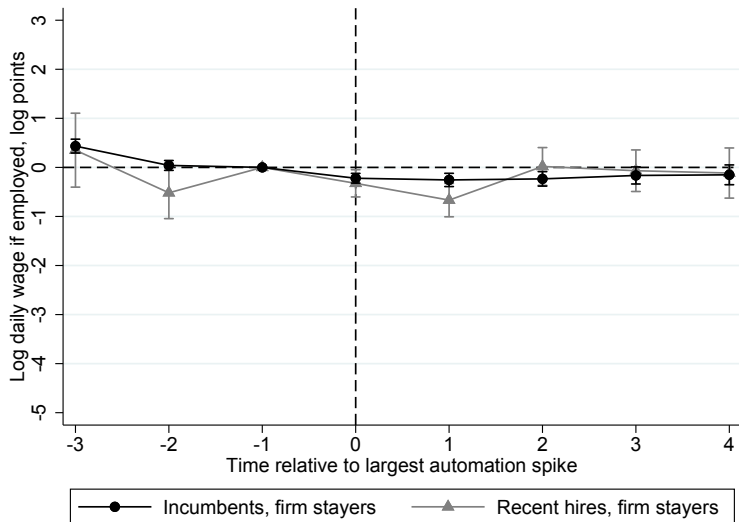
- Coarsened exact matching: separate strata for each 5 percentiles of real annual wage income + separate bins for the 99th and 99.5th percentiles, + bin for zero income for recent hires, in each of the three pre-treatment years, while additionally requiring matched workers to be observed in the same calendar year, and work in the same sector one year prior to treatment.
- 30,247 strata for incumbents and 82,942 strata for recent hires
- 98% of treated incumbents are matched; and 93% of control group incumbents are assigned a non-zero weight
- 95% of treated recent hires are matched; and 65% of control group recent hires are assigned a non-zero weight

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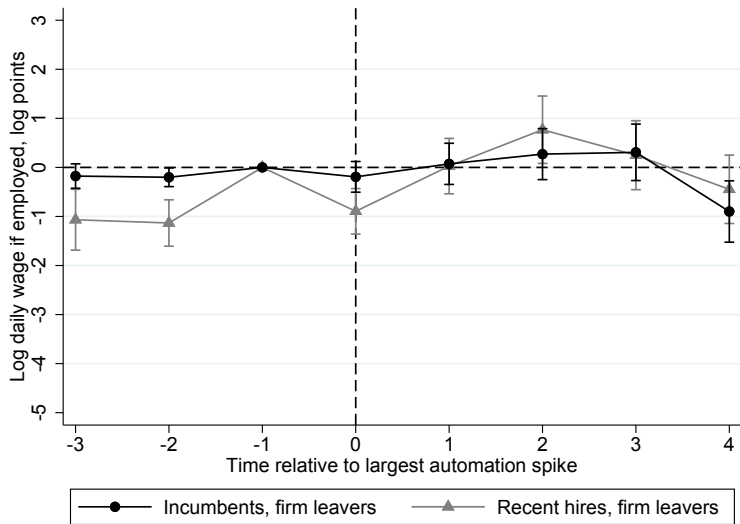
## Scaling the annual wage earnings impacts [◀ Go Back](#)

- **Incumbents:** over 5 years, 8.2% of an annual gross income lost due to automation
- **Recent hires:** over 5 years, 4.4% of an annual gross income gained due to automation
- **100 euros of automation expenditure** during a spike results in:
  - 0.5 euros of income **lost** in the event year, and **6 euros after 5 years**, for an **incumbent worker**.
  - 0 euros of income **gained** in the event year, and **0.6 euros after 5 years**, for a **recent hire**.

## Daily wage effects for stayers



## Daily wage effects for leavers



# Effect heterogeneity by age-specific wage quartile

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	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Bottom quartile (ref)	-0.94* (0.39)	4.25*** (0.27)	2.75*** (0.43)	0.31 (0.18)	0.05 (0.04)
<i>Deviations from reference group for:</i>					
Second quartile	-0.63 (0.47)	0.99** (0.36)	0.63 (0.57)	-0.68** (0.21)	0.27*** (0.07)
Third quartile	-0.78 (0.47)	0.97** (0.36)	0.63 (0.57)	-0.48* (0.22)	0.25*** (0.07)
Top quartile	-1.76*** (0.49)	1.33*** (0.37)	1.04 (0.59)	-1.00*** (0.24)	0.22** (0.07)



# Effect heterogeneity by age-specific wage quartile

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	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Bottom quartile (ref)	5.20*** (1.31)	2.33*** (0.33)	-2.24** (0.87)	0.58 (0.44)	-0.01 (0.05)
<i>Deviations from reference group for:</i>					
Second quartile	-4.93** (1.64)	2.29*** (0.48)	3.80** (1.22)	-0.51 (0.55)	0.03 (0.06)
Third quartile	-4.46** (1.56)	7.60*** (0.52)	4.20*** (1.20)	-0.23 (0.53)	0.08 (0.06)
Top quartile	-5.71*** (1.55)	5.66*** (0.52)	4.19*** (1.14)	-1.46** (0.52)	0.17* (0.08)

# Effect heterogeneity by education level

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	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Low education (ref)	-1.98** (0.64)	4.07*** (0.48)	4.36*** (0.83)	0.13 (0.48)	0.05 (0.08)
<i>Deviations from reference group for:</i>					
Middle education	0.24 (0.76)	2.74*** (0.58)	-1.92 (0.99)	-1.43* (0.56)	0.13 (0.09)
High education	0.48 (0.83)	3.54*** (0.60)	-2.62** (0.96)	-1.20* (0.53)	0.04 (0.09)
Panel B. Recent hires					
Low education (ref)	-0.38 (1.35)	4.24*** (0.40)	3.18** (1.13)	-2.69*** (0.55)	0.03 (0.05)
<i>Deviations from reference group for:</i>					
Middle education	2.57 (1.71)	1.24* (0.52)	-4.14** (1.40)	2.17** (0.66)	-0.06 (0.07)
High education	3.52 (1.90)	3.04*** (0.61)	-5.16*** (1.47)	2.75*** (0.69)	-0.03 (0.06)

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Low education (ref)	-0.38 (1.35)	4.24*** (0.40)	3.18** (1.13)	-2.69*** (0.55)	0.03 (0.05)
<i>Deviations from reference group for:</i>					
Middle education	2.57 (1.71)	1.24* (0.52)	-4.14** (1.40)	2.17** (0.66)	-0.06 (0.07)
High education	3.52 (1.90)	3.04*** (0.61)	-5.16*** (1.47)	2.75*** (0.69)	-0.03 (0.06)

# Effect heterogeneity by sector [◀ Go Back](#)

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel A. Incumbents					
Manufacturing (ref)	-1.52*** (0.21)	5.34*** (0.20)	3.89*** (0.35)	0.07 (0.13)	0.35*** (0.06)
<i>Deviations from reference group for:</i>					
Construction	-0.68 (0.50)	-4.03*** (0.41)	-0.06 (0.74)	-0.34 (0.24)	-0.10 (0.15)
Wholesale & retail trade	-1.83*** (0.36)	-1.34*** (0.30)	2.09*** (0.50)	-0.86*** (0.20)	-0.16* (0.07)
Transportation & storage	0.96 (0.54)	1.70*** (0.46)	-1.06 (0.76)	0.25 (0.29)	-0.40** (0.13)
Accommodation & food serv	4.07** (1.33)	-4.59*** (0.95)	-8.63*** (1.45)	0.14 (0.59)	-0.72*** (0.14)
Information & comm	-3.10*** (0.68)	-0.95 (0.57)	-0.82 (0.94)	-2.58*** (0.38)	-0.33** (0.11)
Prof'l, scientific, & techn'l act	-0.95 (0.50)	-0.15 (0.44)	-1.22 (0.70)	-1.40*** (0.27)	0.00 (0.09)
Admin & support act	2.72*** (0.66)	2.35*** (0.48)	-4.40*** (0.76)	0.80* (0.34)	-0.07 (0.08)

# Effect heterogeneity by sector [◀ Go Back](#)

	Annual wage	Firm separation	Non-emp. days	Log wage	Early retirem.
Panel B. Recent hires					
Manufacturing (ref)	0.80 (0.93)	4.80*** (0.56)	0.02 (1.02)	-0.08 (0.39)	-0.11 (0.06)
<i>Deviations from reference group for:</i>					
Construction	-5.61*** (1.45)	3.54*** (1.02)	5.29** (1.71)	-1.47* (0.66)	0.39* (0.16)
Wholesale & retail trade	-1.93 (1.26)	2.72*** (0.72)	4.27** (1.32)	0.24 (0.51)	0.20** (0.07)
Transportation & storage	3.37 (1.96)	-2.69** (0.96)	-1.76 (1.86)	-1.23 (0.75)	0.11 (0.12)
Accommodation & food serv	5.94 (3.67)	-9.40*** (1.41)	-5.57 (2.91)	2.00 (1.25)	-0.10 (0.15)
Information & comm	-6.17*** (1.80)	-1.06 (0.99)	3.78* (1.84)	-1.01 (0.71)	0.16* (0.08)
Prof'l, scientific, & techn'l act	-4.34** (1.59)	-1.35 (0.90)	3.60* (1.66)	-1.30* (0.64)	0.29** (0.09)
Admin & support act	1.79 (1.24)	1.23* (0.61)	0.08 (1.20)	0.28 (0.48)	0.15* (0.07)