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Technological adoption and Firm Resilience: Understanding the Economic Impact of New Digital Technologies

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Motivation

- Recent literature has pointed out the positive impact of **New Digital Technologies (NDT)**
  - **on firms' performance overall**, according to heterogeneous application across economic sectors and the different ways of shaping production processes (Cirillo et al., 2024)
  - **on enhancing firms' ability to withstand crises** by bolstering their stability and their competitive advantage (Conz and Magnani, 2020; Hillmann and Guenther, 2021)
- **Digital technologies can also shape innovation trajectories in times of crisis** ("crisis-induced innovation") as it was the case of digitalization adoption during the COVID pandemic (Crespo et al., 2023) → innovation during a recession is faster than innovation in normal times, less ambitious and more necessity-based in terms of strategic objectives.
- **Innovative firms are often better equipped to adapt to changes** and sustain their competitive advantage as a necessary precondition for resilience (Reinmoeller and van Baardwijk, 2005; Lien and Timmermans, 2024; de Carvalho et al., 2016; Hamel and Valikangas, 2003)

Literature and research gaps

- ***Resilience*** can be defined as the ability of a firm to **resist and adapt in the presence of an unexpected and potentially disruptive event**, maintaining its assets and organizational structure intact (Conz and Magnani, 2020; Santoro et al., 2021) or to **minimize falls in performance** caused by disruptive events (Dimitriadis, 2021; Williams et al.,2017)
- Despite the increasing body of literature examining **digitalization and resilience during the COVID-19 pandemic, significant research gaps remain** (Iftikhar et al., 2021)
  - *Regional or industry-level studies*, often lacking detailed information on firm-level adoption of digital technologies across sectors (Abidi et al., 2022; Copestake et al., 2024).
  - Studies focusing on *contingent adoption of technologies during the pandemic*, rather than assessing the prior levels of technology adoption e.g. crisis-induced innovation (Lien and Timmermans, 2024); "creative adoption" (Antonelli, 2006)
  - *Evidence form surveys conducted during the pandemic*, which often had limited sample sizes and provided a generalized definition of digitalization (Bianco et al., 2023, Rapaccini et al., 2020).
  - Literature has also *overlooked the comparison* between *the advantages of technological complementarity* adopting technology bundles vs. single technologies, particularly regarding their effects on firms' performance (Battaglia et al., 2023)

Research hypothesis

***Resilience* in this analysis**: the ability of firms to undergo smaller losses in terms of turnover, employment, labour productivity in 2020 (COVID-19 shock)

HP 1 - Digitalization

Investment in **New Digital Techs** (prior to the shock) increases firm resilience to the shock, compared to non-digital investors

HP 2 - Breadth of technological adoption

The combined adoption of **two or more** new digital technologies increases firm resilience, compared to the adoption of a **single technology**

HP3 - Complementarities

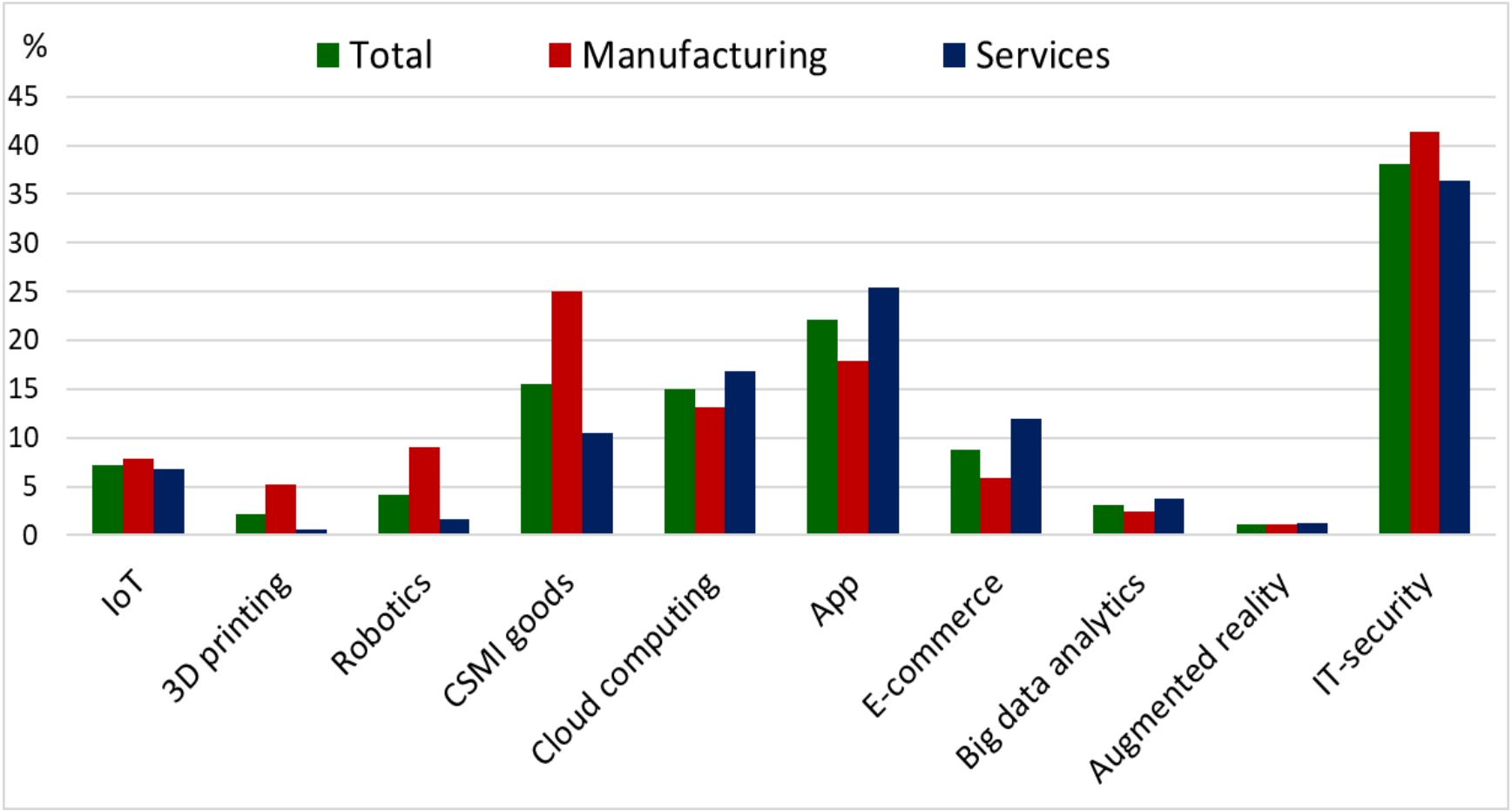
Firms that exploit **complementarities** between *machine-based* and *non-machine-based* technologies (Balsmeier & Woerter, 2019) are more resilient to shocks, compared to firms investing in a single type of technology

Data

- **ISTAT "Rilevazione sulle tecnologie dell'informazione e della comunicazione nelle imprese"** (ICT survey), 2018 edition (reference period **2016-2017**)
  - Representative sample of firms with at least 10 workers, all >250 workers companies
  - **Sectors**: manufacturing and business services (from C to N, NACE sections). Construction sector excluded→from #20,606 firms to #17,714 firms
  - **Technological adoption**: investment in ICT material/non-material goods/services in 2016- 2017
  - **ICT**: IoT, 3D printing, Robotics, Cloud computing, Big Data analytics, Augmented reality, IT security, E-commerce, Apps and Computerized / sensors-managed interconnected goods.
- **ISTAT Asia-Employment Register (LEED), 2014-2020**: employees characteristics (age, gender, education level, employment contract, professional qualification)
- **ISTAT RACLI Register (LEED), 2014-2020**: tenure of employees
- **ISTAT FRAME-SBS Register (firm-level), 2014-2020**: firms' economic activity (import/export activity; business group membership) and performance (e.g. value added, EBITDA)
- **ISTAT ASIA-Active firms Register (firm-level), 2014-2020**: firms' structural information (e.g. geographical location of companies' headquarters; NACE rev 2.2 industry; firm age)

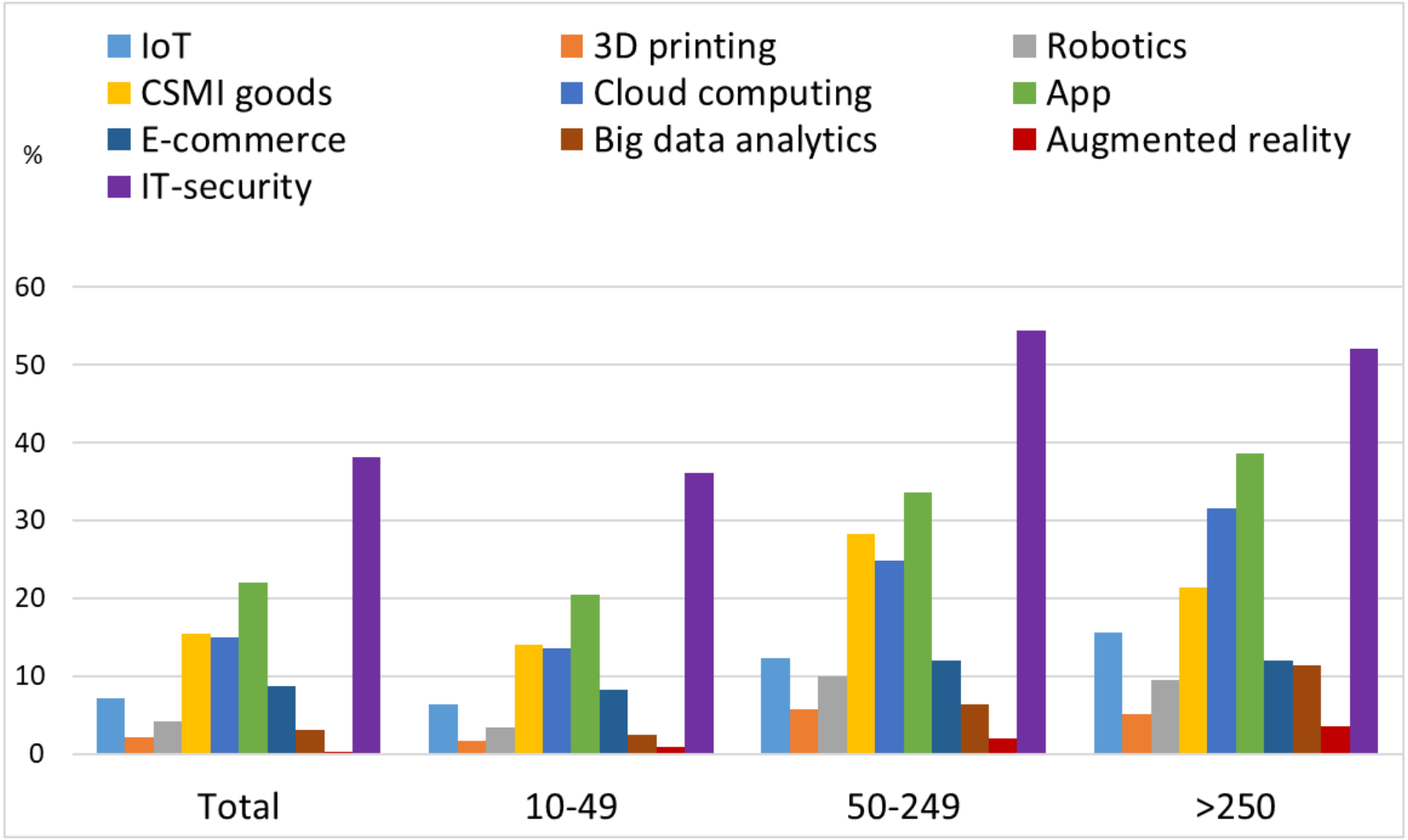
Adoption of NDTs by macro-sector

Share of adoption of each technology are computed with respect to total economy and macro-sector. **ICT 2018 sample**, weighted observations.



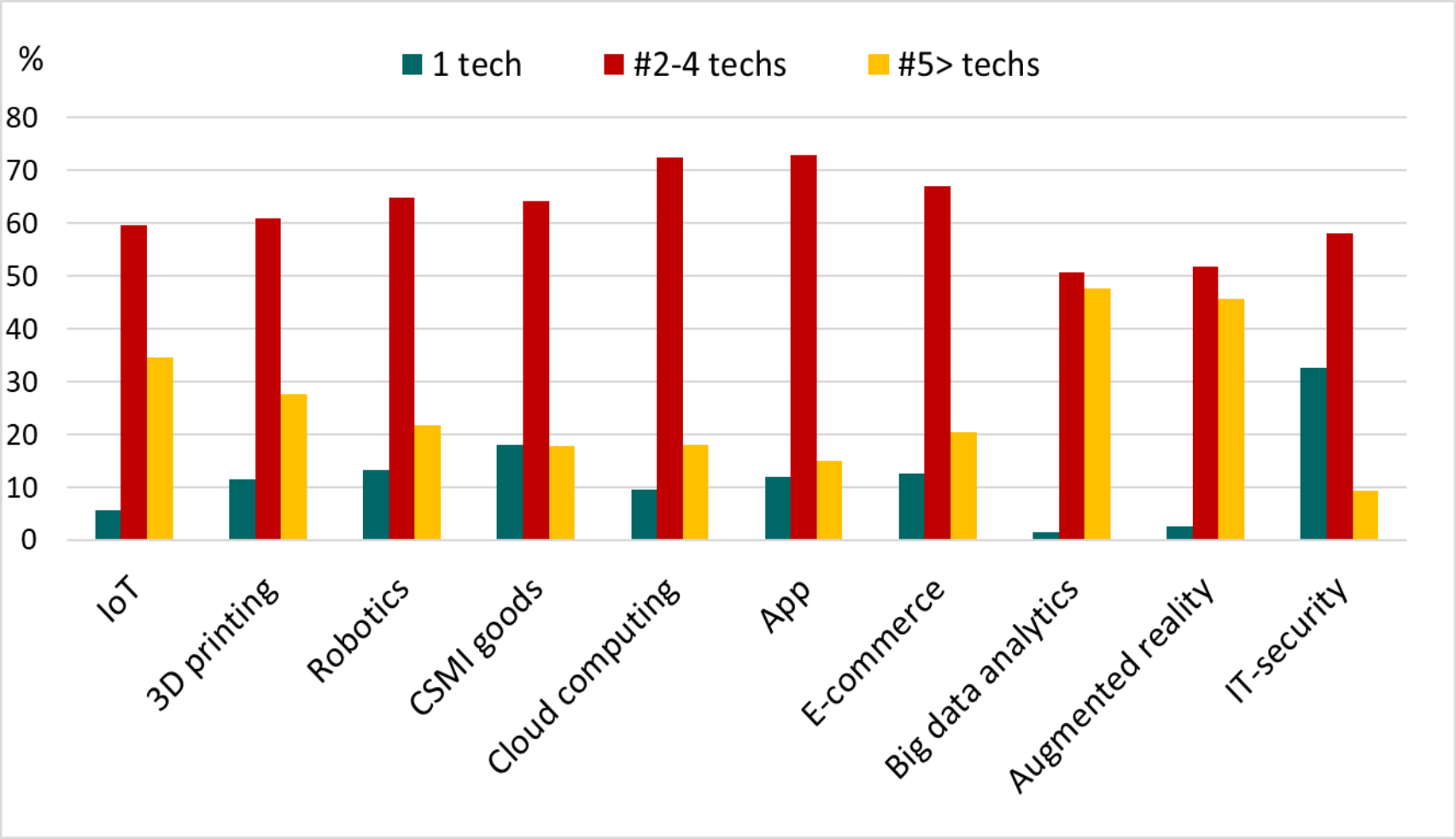
Adoption of NDTs by size

Share of adoption of each technology are computed with respect to total economy and to the total by size class. Multiple techs adoption are allowed. **ICT 2018 sample**, weighted obs.



Breadth of digitalization: NDTs adoption in bundles

Share of single/multiple adopters for each type of adopted technology. The percentages refer to the total number of adopters in each NDT. **ICT survey 2018 sample**, weighted observations.



Empirical strategy (I)

- **1-to-1 nearest neighbour Propensity Score Matching** (PSM) without replacement (Rosenbaum and Rubin, 1983; 1985; Engel et al., 2019; Czarnitzki et al., 2011).
  - Panel PSM → in each year until 2019 included
  - PSM control variables: Italian regions, the NACE 1-digit sectors, firm age classes, growth of firms' size (in log) and growth of firms' value added (in log).

- **Difference-in-Differences**

$$Y_{i,t} = \alpha + \beta_1 \boldsymbol{T_i} + \beta_2 year2020 + \beta_3 \boldsymbol{T_i} * year2020 + \gamma X_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t}$$

$Y_{i,t}$: alternatively, **turnover / employment / productivity (HIST transformation)**

T_i: **key explanatory variable** taking value 1 if the firms adopted NDT in 2016-2017 and 0 otherwise

$X_{i,t}$: firm-level controls, firm characteristics (size, EBITDA, multinational, Italian/foreign group, public control, NACE 2-digit industries, NUTS 2 regions) workforce information (age, gender, education, professional qualification (e.g. managers, blue collars), tenure, working-hour regime, work contract)
t = 2014-2020

Empirical strategy (II)

- **Main HP**
  - HP 1: T_i**=1** if the firm adopted (whatever or except IT security) one NDT in 2016-2017, T_i**=0** if is a non-adopter in 2016-2017
  - HP 2: T_i**=1** if the firm is a single-NDT adopter in 2016-2017, T_i**=0** = 0 if adopted at least two NDT in 2016-2017
  - HP 3: T_i**=1** if the firms adopted both machine-based NDT (IoT, 3D Printing, Robotics, Augmented Reality and CSMI goods) and non-machine based NDT (Cloud Computing, Big Data Analytics, Apps and IT security) (Balsmeier and Woerter, 2019) in 2016-2017, T_i**=0** if adopted one of out of them
- **Heterogeneity**
  - by digital technology: T_i**=1** if adopting IoT/Robotics/Big Data/ Other computerized / sensors-managed and interconnected (CSMI) goods in 2016-2017, T_i**=0** if it is a non-adopter
  - by economic sector: split-sample estimates by manufacturing/services
- **Robustness**
  - Placebo test, year of crisis 2016/2017
  - Lock-down of specific industries
  - Any digital technologies

1. Main hypothesis

Results - HP1 Digitalization

- The COVID-19 pandemic led to a significant decline in turnover, employment, and productivity across all firms.

- Firms that had previously adopted *one digital technology* undergo losses not different than firms without any prior technology adoption

Table 1- DID fixed effects estimate: Single technology adoption vs. Non-adopters

	Turnover	Employment	Productivity
year2020	-0.227***	-0.0466***	-0.559***
	(0.0277)	(0.00764)	(0.0738)
Single Tech Adoption * year2020	0.0270	0.00831	-0.129
	(0.0244)	(0.00813)	(0.0929)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.79***	1.128***	7.478***
	(0.437)	(0.202)	(1.028)
N of Obs	34627	34628	34627
N of firms	6964	6964	6964
R^2	0.038	0.459	0.144

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (by education, age, gender, tenure, professional, part-time, temporary contract), firm's characteristics (size, EBITDA, firm-age, public control, multinationals, groups; NACE 2-digit; NUTS 2). Dependent variables are HIST transformed. Clustered robust standard errors (at firm level) in parentheses. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Results - HP1 Digitalization, accounting for the role of IT-security

- Firms that had previously adopted *one digital technology different than IT security* do not undergo smaller losses than firms without any prior technology adoption

Table 2 - DID fixed-effect estimates: Single technology adoption except IT-security vs. non adopters/only IT-security adopters

	Turnover	Employment	Productivity
year2020	-0.244***	-0.0517***	-0.562***
	(0.0398)	(0.0119)	(0.104)
Single Tech Adoption * year2020	0.00799	0.0171	-0.210
	(0.0391)	(0.0126)	(0.145)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.25***	1.532***	11.15***
	(2.731)	(0.215)	(0.823)
N of Obs	14590	14590	14590
N of firms	2938	2938	2938
R^2	0.141	0.491	0.054

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (by education, age, gender, tenure, professional, part-time, temporary contract), firm's characteristics (size, EBITDA, firm-age, public control, multinationals, groups; NACE 2-digit; NUTS 2). Dependent variables are HIST transformed. Clustered robust standard errors (at firm level) in parentheses. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Results - HP2 Breadth of digitalization

- Firms adopting a single technology were significantly more impacted by the crisis than adopters of at least 2 NDT in 2016-2017

- Statistically significant effect of losses mitigation in terms of both turnover, employment and productivity

Table 3 - DID FE estimate: Single technology adoption vs. at least #2 techs

	Turnover	Employment	Productivity
year2020	-0.131***	-0.0317***	-0.394***
	(0.0208)	(0.00826)	(0.0799)
Single Tech Adoption * year2020	-0.0545***	-0.0151*	-0.298***
	(0.0206)	(0.00785)	(0.0926)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.74***	1.273***	10.49***
	(2.529)	(0.181)	(2.374)
N of Obs	34653	34653	34653
N of firms	6970	6970	6970
R^2	0.159	0.467	0.036

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (by education, age, gender, tenure, professional, part-time, temporary contract), firm's characteristics (size, EBITDA, firm-age, public control, multinationals, groups; NACE 2-digit; NUTS 2). Dependent variables are HIST transformed. Clustered robust standard errors (at firm level) in parentheses. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Results – HP3 Complementarity

- Firms adopting **both machine-based** (IoT, 3D Printing, Robotics, Augmented Reality and CSMI goods) and **non-machine-based techs** (Cloud Computing, Big Data Analytics, Apps and IT security) exhibit smaller losses due to the COVID-19 crisis than those adopting only non-machine or only machine digital technologies

Table 4 - DID FE estimate: M&NM techs vs only NM techs or Machine techs

	Turnover	Employment	Productivity
year 2020	-0.0994***	-0.0104	-0.489***
	(0.0192)	(0.00758)	(0.0674)
Treatment * year 2020	0.0413***	0.0192***	0.176**
	(0.0147)	(0.00618)	(0.0684)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	14.12***	1.839***	7.744***
	(0.365)	(0.178)	(1.063)
N of Obs	43665	43665	43665
N of firms	8774	8774	8774
R^2	0.172	0.515	0.042

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (by education, age, gender, tenure, professional, part-time, temporary contract), firm's characteristics (size, EBITDA, firm-age, public control, multinationals, groups; NACE 2-digit; NUTS 2). Dependent variables are HIST transformed. Clustered robust standard errors (at firm level) in parentheses. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

2. Heterogeneity by technology and by sector

Heterogeneity by technology: HP1 technology-specific

	Robotics			IoT			Big Data Analytics		
	Turnover	Employment	Productivity	Turnover	Employment	Productivity	Turnover	Employment	Productivity
year2020	-0.153***	0.00896	-0.344***	-0.191***	-0.0369***	-0.653***	-0.198***	-0.00443	-0.331***
	(0.0392)	(0.0116)	(0.109)	(0.0339)	(0.0111)	(0.0837)	(0.0526)	(0.0128)	(0.111)
Technology Adoption * year2020	0.0651***	0.0309***	0.334***	0.132***	0.0440***	0.193*	0.0812**	0.0218	-0.118
	(0.0204)	(0.00883)	(0.0945)	(0.0270)	(0.0110)	(0.100)	(0.0341)	(0.0136)	(0.153)
Workforce characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	14.45***	2.340***	12.46***	14.66***	2.031***	8.008***	13.69***	2.233***	8.258***
	(0.731)	(0.298)	(1.592)	(0.469)	(0.223)	(1.043)	(0.771)	(0.289)	(1.651)
N of Obs	11085	11085	11085	22466	22466	22466	13606	13606	13606
N of firms	2228	2228	2228	4516	4516	4516	2738	2738	2738
R^2	0.249	0.546	0.114	0.164	0.463	0.054	0.171	0.525	0.036

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Heterogeneity - HP1 split-sample by macro-sectors

- HP1 Single technology adoption (any) vs. Non-adopters
- Single NDT's adoption turns out to mitigate COVID-19 losses just in manufacturing
- Overall evidence driven by services

	Sector Group : Manufacturing			Sector Group: Service		
	Turnover	Employment	Productivity	Turnover	Employment	Productivity
year2020	-0.128***	-0.0227*	-0.222**	-0.292***	-0.0616***	-0.726***
	(0.0292)	(0.0118)	(0.109)	(0.0366)	(0.00990)	(0.0965)
Single Tech Adoption * year2020	0.0571**	0.0293***	0.00975	0.0161	0.000186	-0.189
	(0.0285)	(0.0113)	(0.127)	(0.0316)	(0.0108)	(0.124)
Workforce characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	12.10***	0.506***	10.18***	13.21***	1.423***	8.862***
	(0.775)	(0.178)	(1.593)	(0.403)	(0.149)	(0.907)
N of Obs	7945	7945	7945	24080	24080	24080
N of firms	1631	1631	1631	4889	4889	4889
R^2	0.198	0.524	0.035	0.160	0.527	0.040

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Heterogeneity - HP1 net IT-security split-sample by macro-sectors

- HP1 Single technology adoption, net IT security vs. Non-adopters
- Single NDT's adoption turns out to mitigate COVID-19 losses just in manufacturing

	Sector Group : Manufacturing			Sector Group: Service		
	Turnover	Employment	Productivity	Turnover	Employment	Productivity
year2020	-0.141**	-0.0127	-0.471***	-0.311***	-0.0734***	-0.717***
	(0.0650)	(0.0119)	(0.136)	(0.0537)	(0.0160)	(0.139)
Single Tech Adoption * year2020	0.101**	0.0444***	0.0331	-0.0223	0.00238	-0.310
	(0.0474)	(0.0162)	(0.211)	(0.0530)	(0.0168)	(0.197)
Workforce characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	11.21***	1.190***	4.615	13.59***	1.856***	9.214***
	(1.924)	(0.397)	(3.880)	(0.662)	(0.289)	(1.841)
N of Obs	3587	3587	3587	9901	9901	9901
N of firms	736	736	736	2012	2012	2012
R^2	0.193	0.560	0.049	0.133	0.471	0.055

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Heterogeneity – HP2 breadth of digitalization, split-sample by macro-sectors

- HP 2: Single technology adoption vs. Adopters of at least 2 technologies
- The breadth of digitalization is statistically relevant in services sector (→additional decline if single-adopters)

	Sector Group : Manufacturing			Sector Group: Service		
	Turnover	Employment	Productivity	Turnover	Employment	Productivity
year2020	-0.0726**	-0.00954	-0.101	-0.155***	-0.0381***	-0.549***
	(0.0311)	(0.0120)	(0.114)	(0.0232)	(0.0107)	(0.106)
Single Tech Adoption * year2020	0.00578	0.0115	-0.139	-0.0926***	-0.0285***	-0.354***
	(0.0247)	(0.0101)	(0.122)	(0.0247)	(0.0103)	(0.124)
Workforce characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	13.63***	1.244***	10.08***	13.58***	1.229***	8.872***
	(0.987)	(0.247)	(2.263)	(0.375)	(0.192)	(1.368)
N of Obs	7982	7982	7982	24087	24087	24087
N of firms	1645	1645	1645	4888	4888	4888
R^2	0.224	0.580	0.049	0.149	0.435	0.038

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

3. Robustness

Robustness - HP1 Placebo test (treatment year 2016)

- HP1: Single technology adoption vs. Non-adopters

	Turnover	Employment	Productivity
Post-treatment ≥ 2016	-0.214***	-0.0442***	-0.609***
	(0.0239)	(0.00715)	(0.0692)
Single Tech Adoption * Post-treatment ≥ 2016	0.000941	0.00310	-0.0230
	(0.0159)	(0.00619)	(0.0571)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.80***	1.129***	7.450***
	(0.437)	(0.202)	(1.028)
N of Obs	34627	34627	34627
N of firms	6964	6964	6964
R^2	0.144	0.459	0.038

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Robustness - HP2 Placebo test (treatment year 2016)

- HP2: Single technology adoption
  vs.
  at least #2 other technologies

	Turnover	Employment	Productivity
Post-treatment $\geq$ 2016	-0.152***	-0.0376***	-0.545***
	(0.0195)	(0.00784)	(0.0740)
Single Tech Adoption * Post-treatment $\geq$ 2016	-0.0159	-0.00432	-0.0197
	(0.0159)	(0.00608)	(0.0574)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.74***	1.271***	10.46***
	(0.536)	(0.181)	(2.535)
N of Obs	34653	34653	34653
N of firms	6970	6970	6970
R^2	0.159	0.466	0.036

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Robustness - HP3 Placebo test (treatment year 2016)

- HP3: Machine & non-machine digital technologies vs either Machine or Non-machine techs

	Turnover	Employment	Productivity
Post-treatment ≥ 2016	-0.0468***	0.00003	-0.351***
	(0.0178)	(0.00772)	(0.0776)
Treatment * Post-treatment ≥ 2016	0.0162	0.00154	0.0651
	(0.0170)	(0.00618)	(0.0585)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	14.98***	2.798***	9.278***
	(0.381)	(0.349)	(1.254)
N of Obs	27164	27164	27164
N of firms	5462	5462	5462
R^2	0.245	0.575	0.053

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Robustness - HP1 Accounting for COVID-19 restrictions

- HP1, accounting for the lock-down of non-essential activities industries (Dummy=1 for NACE rev.2 sectors locked-down between March 2020 - May 2020)

	Turnover	Employment	Productivity
year 2020	-0.190***	-0.0534***	-0.354***
	(0.0305)	(0.00866)	(0.0791)
Single Tech Adoption * year 2020	0.0191	0.00628	-0.166*
	(0.0240)	(0.00812)	(0.0919)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.78***	1.118***	7.451***
	(0.437)	(0.203)	(1.028)
N of Obs	34627	34627	34627
N of firms	6964	6964	6964
R^2	0.150	0.460	0.048

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Robustness - HP1, net IT-security, accounting for COVID-19 restrictions

- HP1, net of IT-security, accounting for the lock-down of non-essential activities industries (Dummy=1 for NACE rev.2 sectors locked-down between March 2020 - May 2020)

	Turnover	Employment	Productivity
year 2020	-0.231***	-0.0614***	-0.373***
	(0.0474)	(0.0138)	(0.124)
Single Tech Adoption * year 2020	0.00508	0.0161	-0.221
	(0.0388)	(0.0126)	(0.144)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	12.27***	1.528***	11.32***
	(0.828)	(0.215)	(2.725)
N of Obs	14590	14590	14590
N of firms	2938	2938	2938
R^2	0.144	0.492	0.063

Source: our calculations on Istat data. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Robustness – The Role of Adopting Any Digital Technology

- HP: Prior adoption of <u>at least one digital technology</u> vs. Non-adopters

	Turnover	Employment	Productivity
year 2020	-0.149***	-0.0297***	-0.566***
	(0.0170)	(0.00703)	(0.0618)
Treatment * year 2020	0.0734***	0.0296***	0.242***
	(0.0166)	(0.00712)	(0.0716)
Workforce characteristics	Yes	Yes	Yes
Firms characteristics	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Constant	13.96***	2.049***	5.652***
	(0.443)	(0.175)	(1.586)
N of Obs	47197	47197	47197
N of firms	9552	9552	9552
R^2	0.128	0.438	0.039

Source: our calculations on Istat data. Treatment group is a randoms stratified sample of the 50% of the treatment group. Stratification of the sample conducted on 2-digit NACE, region and size classes. Other controls include: lag of employment, workforce composition (education, age, gender, seniority, profession, contractual category), firm's productive characteristics (2-digits NACE code, NUTS 2 regions, age, international markets, multinationals, groups). Clustered robust standard errors (at firm level) in parentheses.

Summing up and concluding

- **Intensity of digitalization efforts is very important overall**: adopting only one new technology (HP1) insufficient to enhance resilience (*except for manufacturing*)

- **Resilience significantly improves in terms of turnover, employment and productivity when firms invest in a multiple-technology approach,** compared to prior single technology adoption (HP2). This holds for services, not for manufacturing. The intensity of resilience is directly related to the number of technologies

- Based on Balsmeier and Woerter (2019) taxonomy**, the adoption of machine-based ICT besides non-machine based ICT improve the resilience capacity of firms** across the COVID-19 crisis in terms of employment, turnover, and productivity detecting **a significant role for complementarity (HP3)**

- From a **policy perspective, our analysis suggests that comprehensive and integrated innovation policies promoting multi-technology adoption** should be prioritized over isolated incentive schemes that do not encourage the complementary adoption of multiple technologies

grazie

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Laura Bisio & Valeria Cirillo & Matteo Lucchese & Andrea Mina & Stefania Scrofani, 2025. "Technological adoption and Firm Resilience: Understanding the Impact of New Digital Technologies," LEM Papers Series 2025/21 - https://www.lem.sssup.it/WPLem/2025-21.html

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3. Appendix

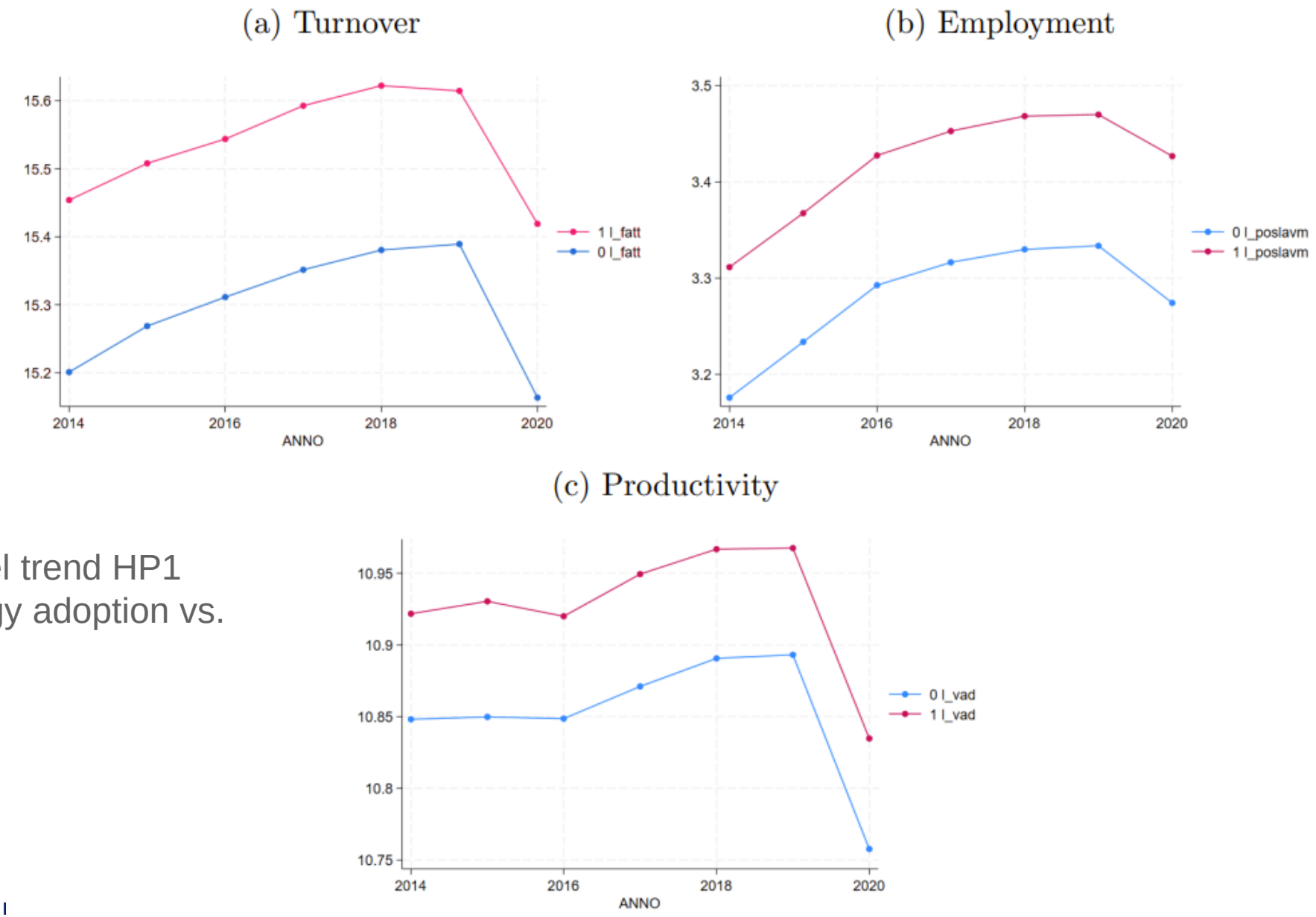

Figure 5: Parallel trend HP1 Single technology adoption vs. Non-adopters

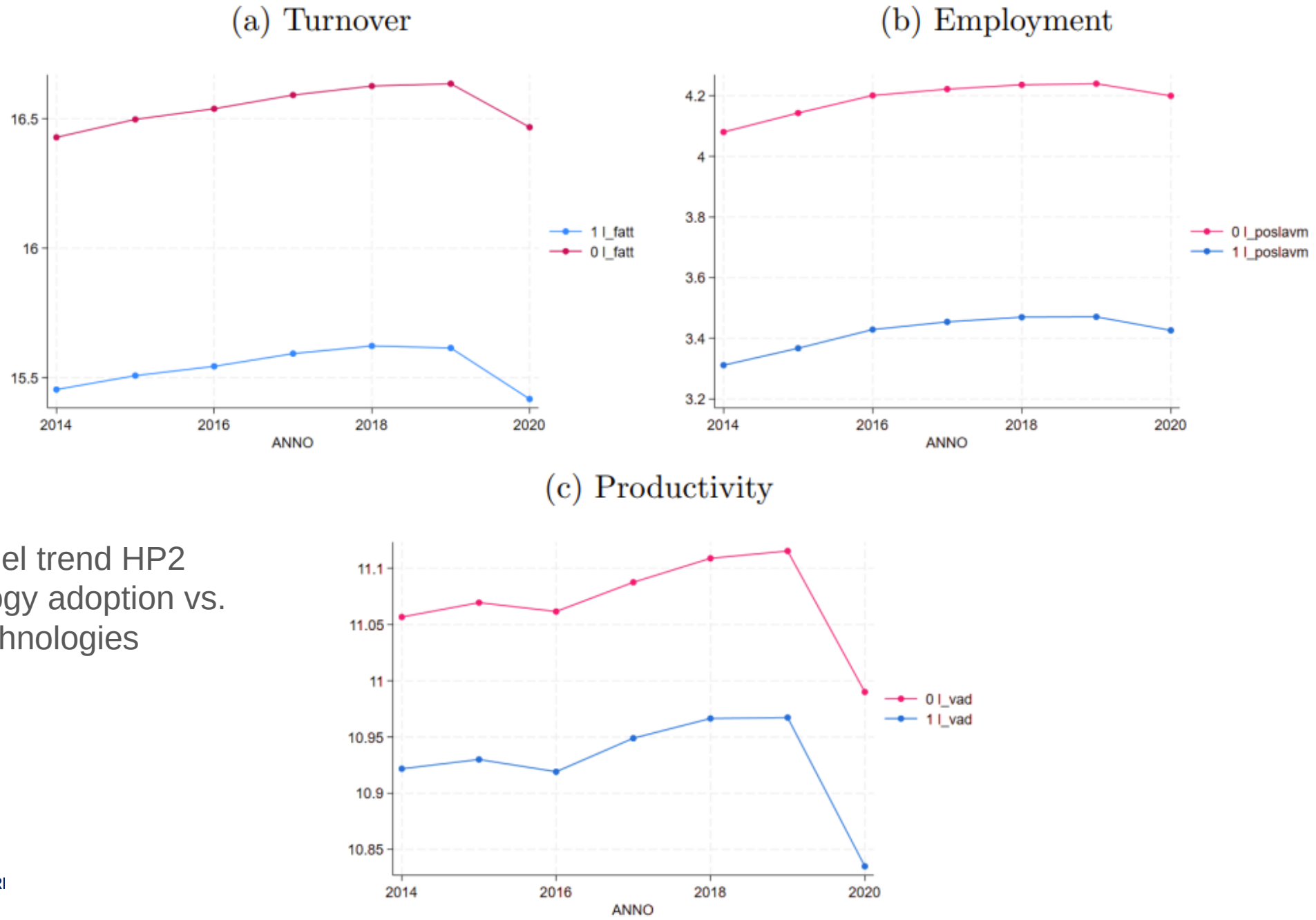

Figure 6: Parallel trend HP2
Single technology adoption vs. at least two technologies adopted

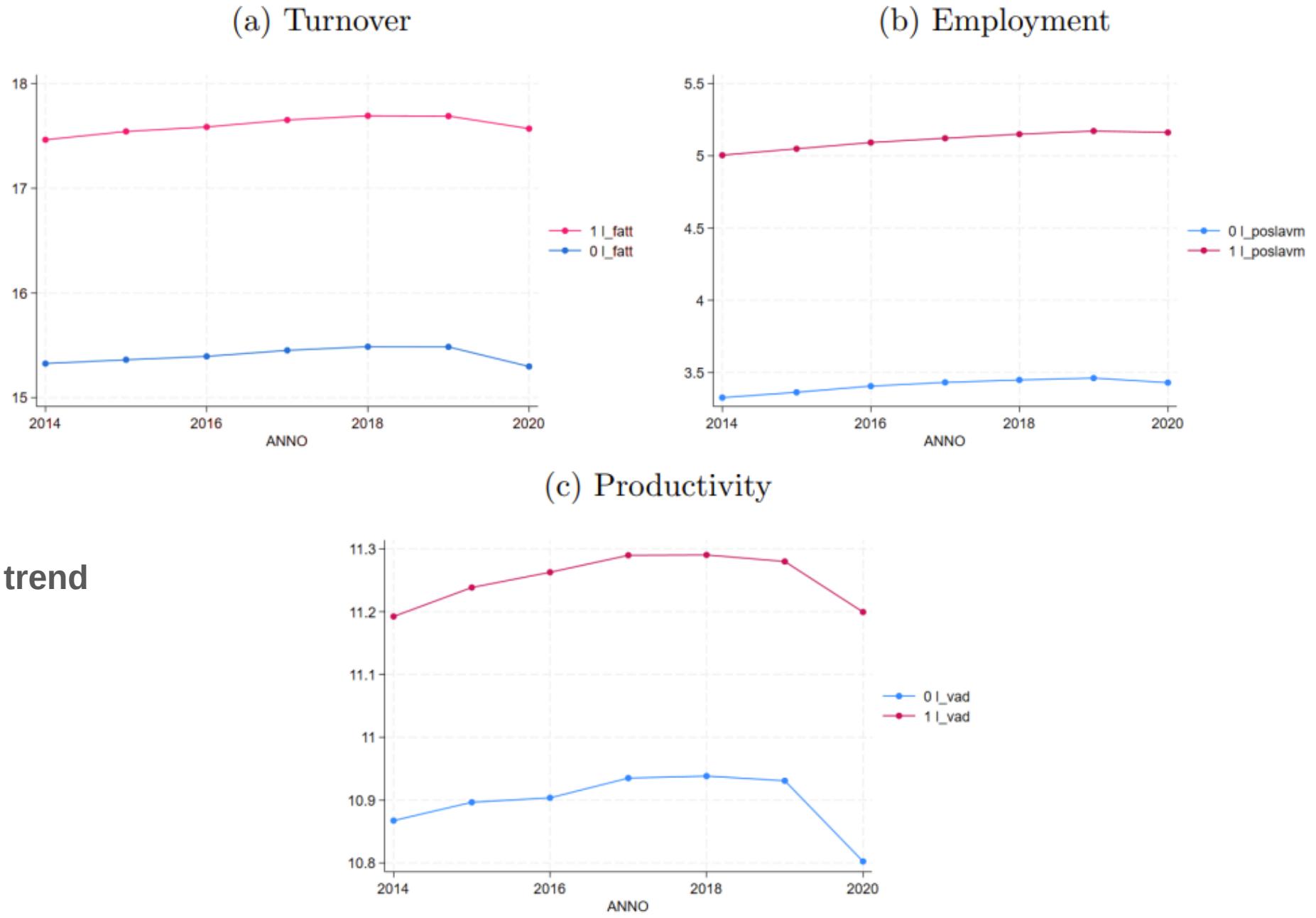

Figure 7: Parallel trend Robotics

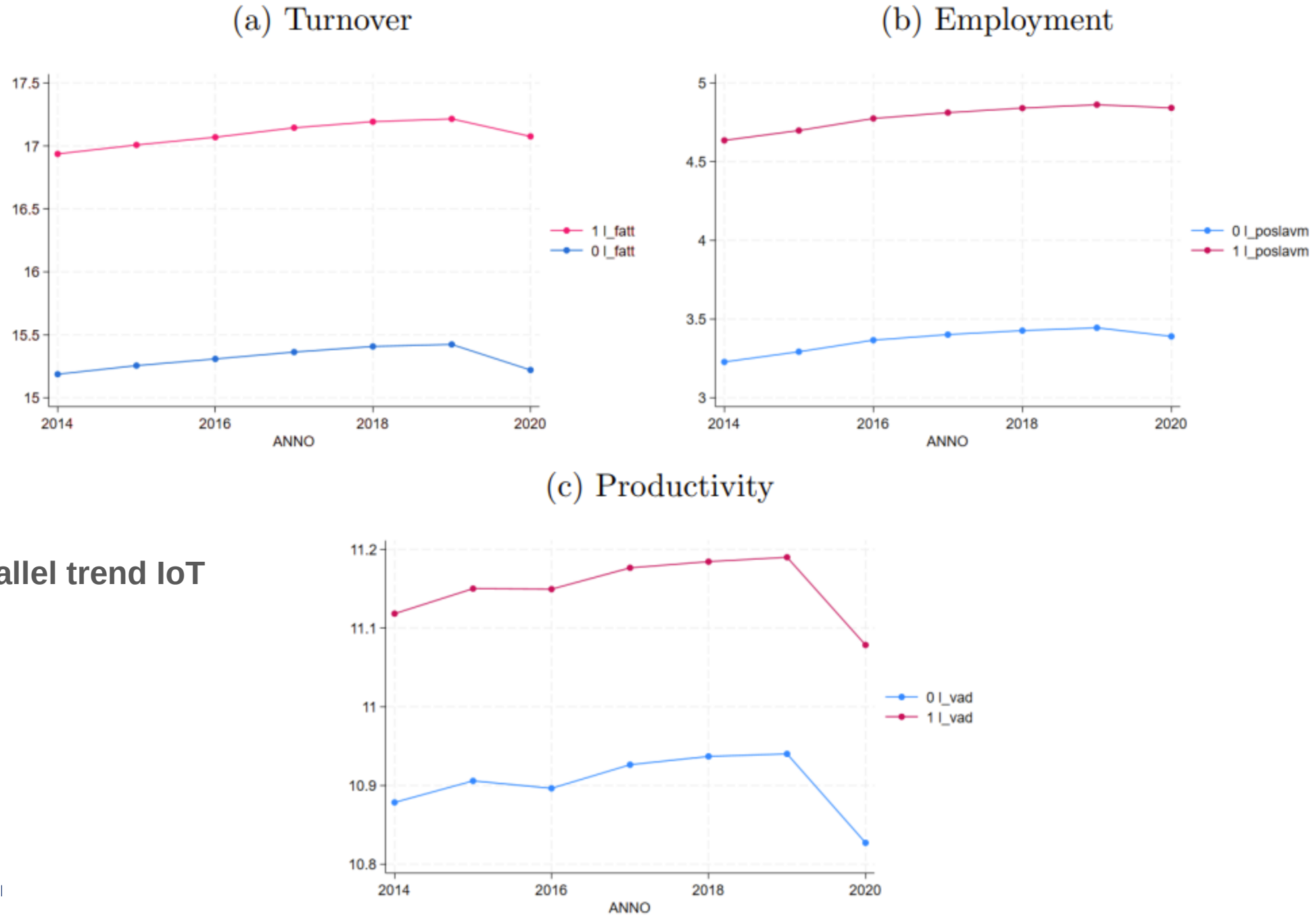

Figure 8: Parallel trend IoT

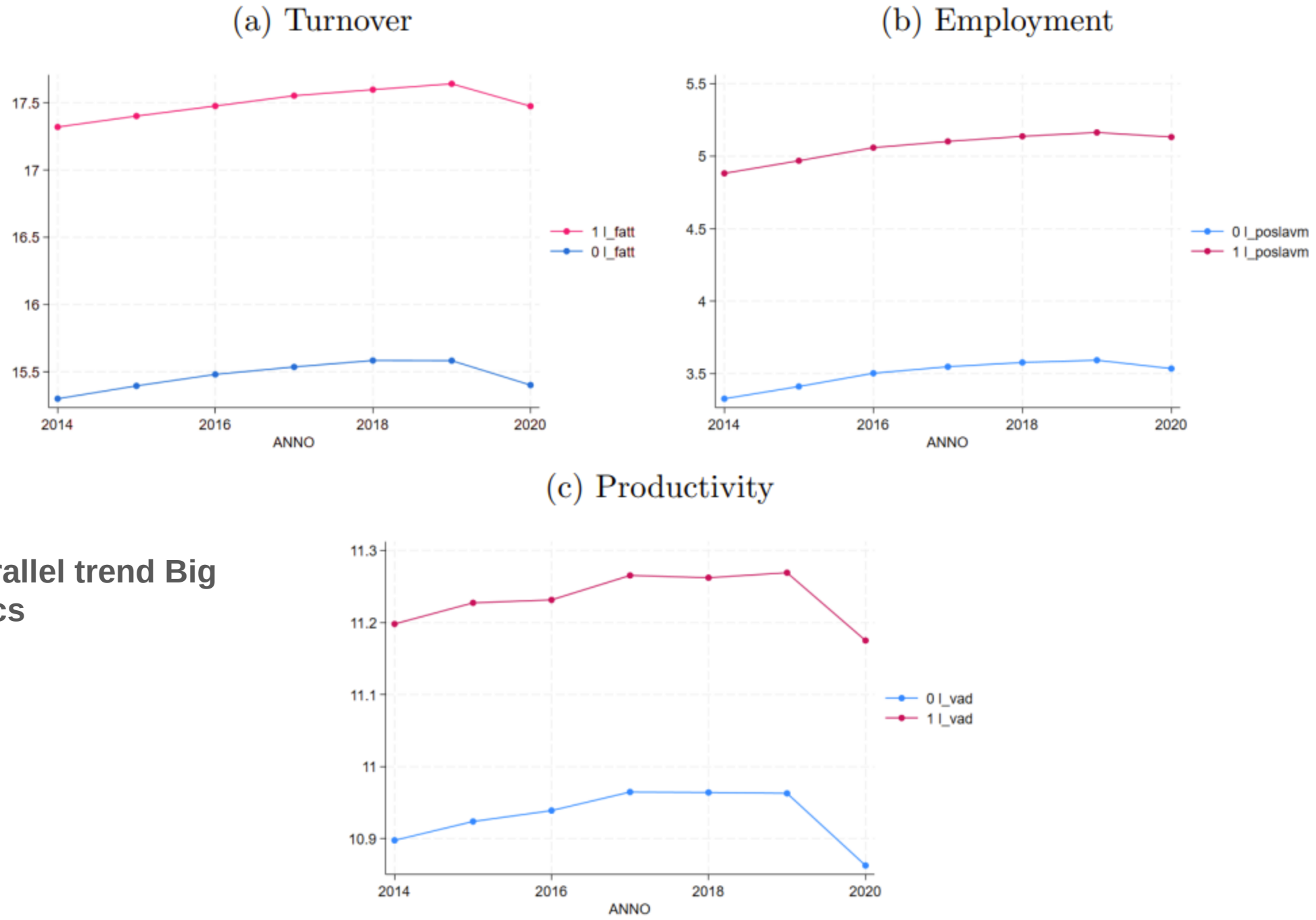

Figure 9: Parallel trend Big Data Analytics

Table 12 - Balance PSM HP1 : Single technology adoption vs Non-adopters

Variable	Unmatched / Matched	Mean: Treated	Mean: Control	% bias	% reduct: |bias|	t-test: t	t-test: $p > \|t\|$
Productivity growth rate 2015	U	.01171	.01443	-0.9		-0.40	0.687
	M	.01171	.00365	2.7	-196.1	1.02	0.306
Productivity growth rate 2016	U	-.00902	-.00561	-1.0		-0.46	0.649
	M	-.00902	-.00047	-2.6	-150.8	-0.93	0.351
Productivity growth rate 2017	U	.02938	.01752	3.8		1.73	0.084
	M	.02938	.0224	2.2	41.2	0.83	0.405
Productivity growth rate 2018	U	.01742	.01382	1.3		0.60	0.551
	M	.01742	.01962	-0.8	38.7	-0.32	0.751
Productivity growth rate 2019	U	.00075	-.00161	0.8		0.36	0.720
	M	.00075	.00249	-0.6	25.7	-0.27	0.791
Employment growth 2015	U	.06404	.07226	-3.4		-1.51	0.131
	M	.06404	.06313	0.4	88.9	0.15	0.878
Employment growth 2016	U	.05885	.06582	-3.6		-1.58	0.115
	M	.05885	.05794	0.5	86.9	0.20	0.840
Employment growth 2017	U	.02532	.02037	3.5		1.52	0.127
	M	.02532	.02379	1.1	69.1	0.43	0.664
Employment growth 2018	U	.01554	.00237	7.7		3.43	0.001
	M	.01554	.01344	1.2	84.0	0.55	0.585
Employment growth 2019	U	.0016	-.00301	2.3		1.04	0.298
	M	.0016	.00382	-1.1	51.7	-0.50	0.615

Table 13 - Balance PSM HP2 Single technology adoption vs at least two technologies adopted

Variable	Unmatched / Matched	Mean: Treated	Mean: Control	% bias	% reduct: |bias|	t-test: t	t-test: $p > \|t\|$
Productivity growth rate 2015	U	.01171	.02051	-2.8		-1.29	0.198
	M	.01171	.01682	-1.6	41.9	-0.66	0.507
Productivity growth rate 2016	U	-.009	-.0013	-3.3		-1.59	0.113
	M	-.009	-.00743	-0.5	84.7	-0.20	0.844
Productivity growth rate 2017	U	.02976	.0231	2.2		1.05	0.292
	M	.02976	.02593	1.2	42.6	0.48	0.631
Productivity growth rate 2018	U	.01758	.01562	0.7		0.35	0.725
	M	.01758	.02132	-1.4	-90.9	-0.57	0.570
Productivity growth rate 2019	U	.00081	-.00068	0.5		0.24	0.810
	M	.00081	.00649	-2.0	-281.5	-0.80	0.426
Employment growth 2015	U	.06404	.07354	-4.1		-1.90	0.058
	M	.06404	.06541	-0.6	85.6	-0.23	0.816
Employment growth 2016	U	.05882	.07597	-8.7		-3.93	0.000
	M	.05882	.0552	1.8	78.9	0.84	0.400
Employment growth 2017	U	.02528	.03549	-7.4		-3.44	0.001
	M	.02528	.02099	3.1	58.0	1.20	0.232
Employment growth 2018	U	.01556	.02625	-6.8		-3.25	0.001
	M	.01556	.01416	0.9	86.9	0.35	0.729
Employment growth 2019	U	.0011	.01684	-9.2		-4.54	0.000
	M	.0011	.00367	-1.5	83.7	-0.57	0.569

Table 14 - Balance PSM Robotics

Variable	Unmatched / Matched	Mean: Treated	Mean: Control	% bias	% reduct: |bias|	t-test: t	t-test: $p > \|t\|$
Productivity growth rate 2015	U	.04618	.01468	10.3		3.03	0.002
	M	.04618	.02923	5.5	46.2	1.27	0.204
Productivity growth rate 2016	U	.02426	-.00445	10.1		2.66	0.008
	M	.02426	.00702	6.1	39.9	1.15	0.249
Productivity growth rate 2017	U	.027	.0177	3.5		0.98	0.326
	M	.027	.03146	-1.7	52.0	-0.31	0.756
Productivity growth rate 2018	U	.00063	.01242	-4.6		-1.37	0.171
	M	.00063	.00319	-1.0	78.3	-0.24	0.810
Productivity growth rate 2019	U	-.01048	-.00247	-2.9		-0.80	0.424
	M	-.01048	-.00738	-1.1	61.2	-0.28	0.781
Employment growth 2015	U	.04396	.07159	-13.2		-3.46	0.001
	M	.04396	.0395	2.1	83.9	0.68	0.499
Employment growth 2016	U	.04084	.057	-10.8		-2.88	0.004
	M	.04084	.04012	0.5	95.5	0.13	0.899
Employment growth 2017	U	.03011	.0188	9.2		2.40	0.016
	M	.03011	.02612	3.2	64.7	0.80	0.425
Employment growth 2018	U	.02867	.00448	17.9		4.58	0.000
	M	.02867	.01735	8.4	53.2	2.79	0.0005
Employment growth 2019	U	.02208	.00021	14.4		3.67	0.000
	M	.02208	.01318	5.8	59.3	1.46	0.145

Table 14 - Balance PSM IoT

Variable	Unmatched / Matched	Mean: Treated	Mean: Control	% bias	% reduct: |bias|	t-test: t	t-test: $p > \|t\|$
Productivity growth rate 2015	U	.03194	.01443	5.1		2.09	0.037
	M	.03194	.02908	0.8	83.7	0.28	0.778
Productivity growth rate 2016	U	.00031	-.00561	1.8		0.69	0.492
	M	.00031	-.00936	2.9	-63.4	0.92	0.359
Productivity growth rate 2017	U	.02708	.01743	3.4		1.31	0.191
	M	.02708	.02997	-1.0	70.1	-0.31	0.760
Productivity growth rate 2018	U	.00789	.0141	-2.3		-0.92	0.359
	M	.00789	.01058	-1.0	56.7	-0.35	0.723
Productivity growth rate 2019	U	.00556	-.0019	2.4		0.95	0.345
	M	.00556	.00318	0.8	68.0	0.27	0.785
Employment growth 2015	U	.0759	.07226	1.5		0.58	0.559
	M	.0759	.07434	0.7	57.0	0.21	0.838
Employment growth 2016	U	.07583	.06534	5.0		1.98	0.048
	M	.07583	.07425	0.8	84.9	0.25	0.806
Employment growth 2017	U	.03695	.02025	11.1		4.36	0.000
	M	.03695	.03524	1.1	89.8	0.38	0.706
Employment growth 2018	U	.02889	.00264	14.9		5.85	0.000
	M	.02889	.02537	2.0	86.6	0.74	0.462
Employment growth 2019	U	.02156	-.00285	13.4		4.99	0.000
	M	.02156	.01795	2.0	85.2	0.66	0.508

Table 14 - Balance PSM Big Data Analytics

Variable	Unmatched / Matched	Mean: Treated	Mean: Control	% bias	% reduct: |bias|	t-test: t	t-test: $p > \|t\|$
Productivity growth rate 2015	U	.03058	.01388	4.9		2.54	0.011
	M	.03058	.02365	2.0	58.5	0.74	0.458
Productivity growth rate 2016	U	.00261	-.00382	2.0		0.98	0.329
	M	.00261	.00505	-0.8	62.1	-0.30	0.763
Productivity growth rate 2017	U	.03026	.02069	3.2		1.57	0.117
	M	.03026	.03841	-2.7	14.9	-1.09	0.274
Productivity growth rate 2018	U	.00879	.01681	-3.0		-1.47	0.141
	M	.00879	.0035	2.0	34.1	0.78	0.437
Productivity growth rate 2019	U	.00394	-.00163	1.8		0.91	0.365
	M	.00394	-.00172	1.8	-1.6	0.72	0.475
Employment growth 2015	U	.08264	.06891	5.7		2.75	0.006
	M	.08264	.08272	0.0	99.5	-0.01	0.992
Employment growth 2016	U	.07915	.06803	5.3		2.59	0.010
	M	.07915	.07862	0.3	95.2	0.09	0.926
Employment growth 2017	U	.03755	.02662	7.1		3.68	0.000
	M	.03755	.03573	1.2	83.3	0.46	0.647
Employment growth 2018	U	.03009	.01326	10.1		5.01	0.000
	M	.03009	.03114	-0.6	93.8	-0.25	0.804
Employment growth 2019	U	.02177	.00411	10.2		4.80	0.000
	M	.02177	.02384	-1.2	88.3	-0.49	0.625