Technological innovation, digital adoption and firm performance

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European Investment Bank

Outline

1 Motivation

2 Data: EIB Investment Survey (EIBIS)

3 Analysis

4 Conclusion

Motivation and Questions

- What is the effect of digital adoption on firm performance?
  - advanced digital technologies (ADT): 3D printing, advanced robotics, drones, augmented or virtual reality, digital platforms, IoT, big data analytics and AI
  - firm performance outcomes: investment in employee training, management practices, innovation, firm productivity
- Investment in digitisation accelerated by COVID-19 (EIB 2023)
  - 53% of EU firms made investments to become more digital as a response to COVID-19
  - to sell products and services online, prevent business disruption, organise remote work, and/or improve communication with customers, suppliers and employees

Structural increase in the use of advanced digital technologies (ADT)

- Rapid increase in the *use* of ADT and *decline* in the price over time
  - Brynjolfsson and McElheran (2016), Graetz and Michaels (2018), Acemoglu and Restrepo (2019), Klump et al. (2021)
- ADT expand the set of tasks within the production process that can be performed by capital
  - which decreases the share of tasks performed by labour, in particular for routine tasks (Acemoglu and Restrepo 2021, Acemoglu et al. 2022)
- Can also increase the productivity of workers in tasks they are already performing or creating new tasks for them

What we do in the paper

- Estimate effect of digital adoption on firm performance outcomes
  - investment in employee training, management practices, innovation, firm productivity
  - using data from the EIB Investment Survey (EIBIS) on 27 EU countries
- Using OLS, propensity score matching and IV
  - IV based on technological innovation (stock of digital patents in the World Corporate Top RD Investors IP database) in upstream and downstream sectors of the firms: similar to a shift-share instrumental variable

Preview of main results - Propensity re-weight (ORBIS)

Dependent: variable	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
Digital	0.307***	0.455***	0.325***	0.044***	0.079***	0.038***	0.053***
	(0.020)	(0.018)	(0.021)	(0.004)	(0.015)	(0.014)	(0.012)
Observations	38,187	42,145	36,007	36,011	37,482	36,185	40,456
R-squared				0.069	0.339	0.438	0.374
Pseudo R2	0.0951	0.177	0.0737				

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Data

DATA: The EIB Investment Survey (EIBIS)

- Since 2016, annual survey of about 13,350 non-financial enterprises in all 27 EU countries and the US (since 2019)
  - non-financial enterprises with 5+ employees
  - interviews of senior persons with responsibility for investment decisions and how they are financed (owner, CEO or CFO)
  - NACE categories C to J: manufacturing, construction, services (wholesale and retail trade, accommodation and food services), and infrastructure (electricity and gas, water supply and waste management, transportation and storage, information and communication)
- Information on firm characteristics and performance, past investment activities and future plans, sources of finance, and challenges that businesses face

EIBIS sampling strategy

- EIBIS sample stratified disproportionally by country, industry group (sector) and firm size classes, and stratified proportionally by region within each country
  - each year sample size ranges from 180 firms in Cyprus, Luxembourg and Malta to 600 in France, Germany, Italy, Spain and the UK, and 800 in US
- EIBIS includes a panel component and a top-up sample
  - panel firms (approx. 40% in each wave): participated in a previous wave of the survey, and consented to be re-contacted in the following wave
  - top-up sample: firms that did not participate in the preceding wave

EIBIS - question on the use of advanced digital technologies

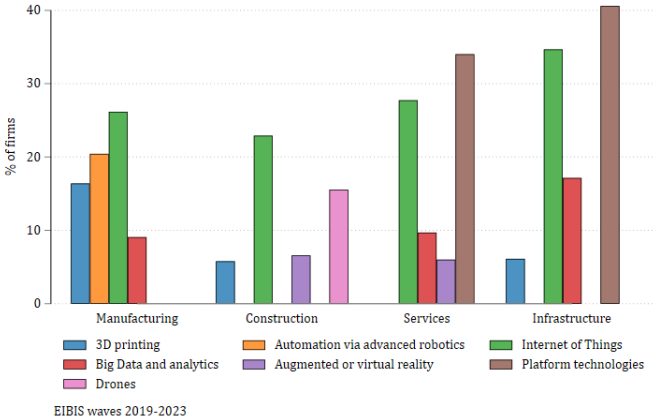
- Since wave 4, EIBIS includes questions on the adoption of four advanced digital technologies that are revelant to the sector in which the firm is operating
- "To what extent, if at all, are each of the following digital technologies used within your business? Please say if
  - you do not use the technology
  - used it in parts of the business within your business
  - or whether your entire business is organised around this technology?"

EIBIS - Timing

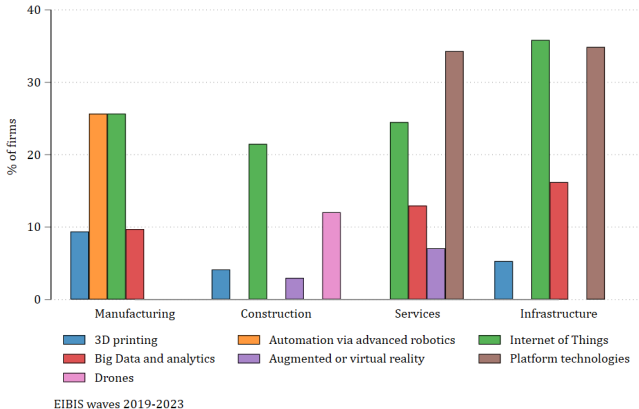
...	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Orbis	Orbis	Orbis EIBIS	Orbis EIBIS	Orbis EIBIS	Orbis EIBIS Digital	Orbis EIBIS Digital A	Orbis EIBIS Digital A	Orbis EIBIS Digital	EIBIS Digital	

Digital: Digital nodule introduced in EIBIS.
A: Question on timing of technology adoption.

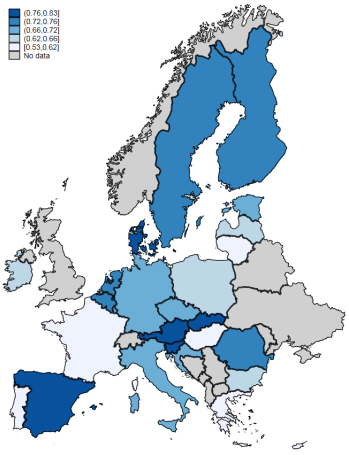
Advanced digital technologies in EIBIS



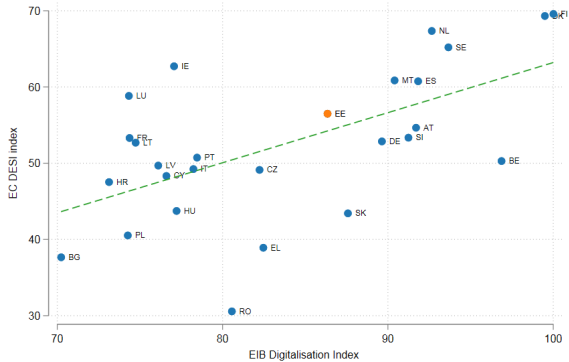
Advanced digital technologies in EIBIS: Estonia



Digitisation - Cross country distribution

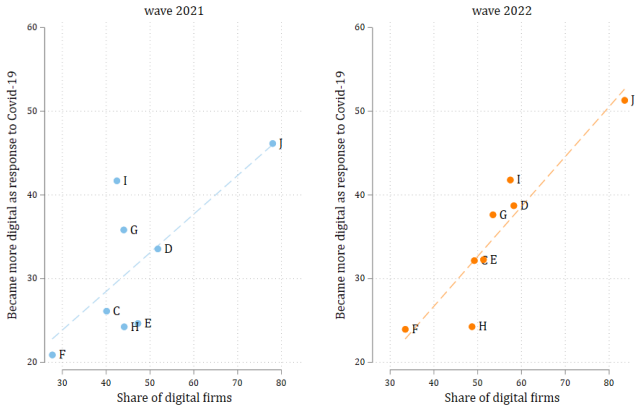


How EIBIS inference compare?



Desi: Digital Economy and Society Index

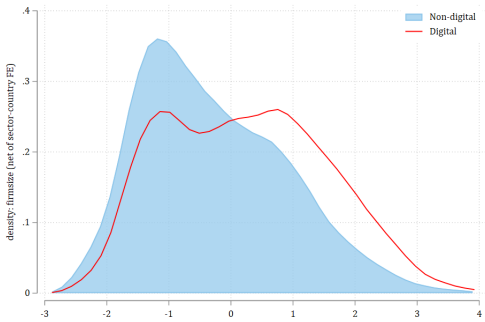
Important dynamic: Covid impact!



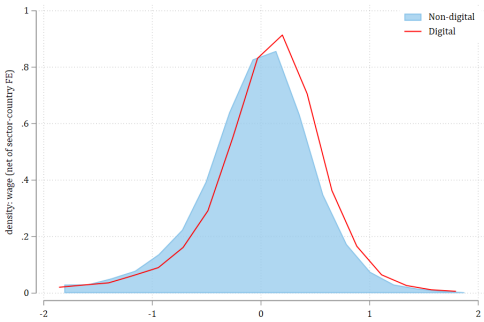
How different are digital firms?

Firms that use digital technologies tend to be larger and pay better

Firm size

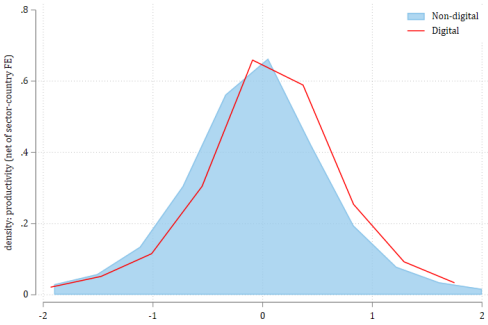


Average wage

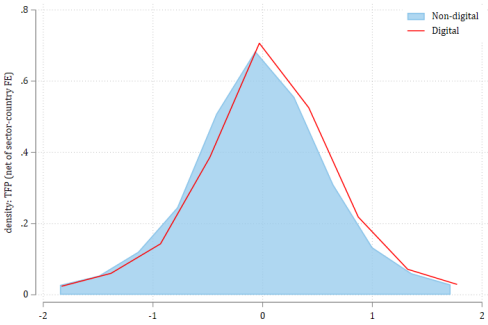


Firms that use digital technologies tend more productive

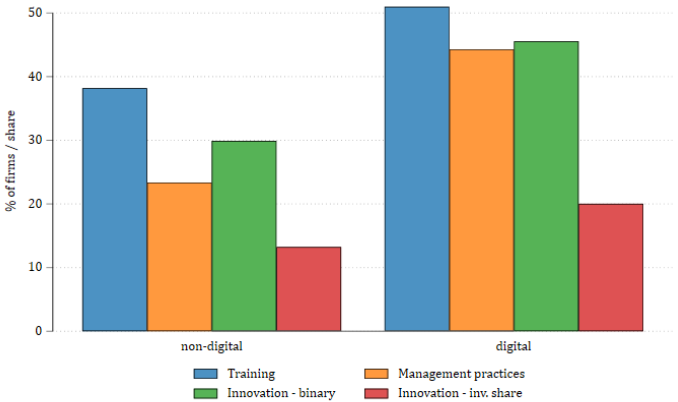
Labour productivity



TFP



Firms that use digital technologies perform better on various outcomes



Analysis

Modelling outcomes of Digital adoption

$$Y_{it} = \alpha + \beta DigitalAdoption_{it} + \boldsymbol{\tau X_{it}} + \mu_c + \gamma_t + \delta_s + \epsilon_{it} \quad (1)$$

- where $DigitalAdoption_{it}$ refers to binary digital adoption variable which takes value of 1 if firm adopted digital technologies by t.
- Y_{it} is one of the following variables: log labor productivity, log TFP, log average wage, training and management practices (firms are asked whether they adopted strategic business monitoring system or not), innovation investment (binary and share) for firm i in country c operating in sector s at time t.

First results

Dependent: variable	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
Digital	0.337***	0.462***	0.319***	0.044***	0.105***	0.061***	0.084***
	(0.015)	(0.013)	(0.015)	(0.003)	(0.010)	(0.009)	(0.008)
	(0.006)	(0.006)	(0.007)	(0.004)	(0.009)	(0.009)	(0.007)
Observations	53,394	58,334	49,199	49,203	50,800	48,917	55,497
R-squared	0.0972	0.168	0.0609	0.058	0.341	0.400	0.379

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

- Can our results be interpreted as causal? No.
- If already, bigger better, etc firms choose to digitalise, we cannot call these measurements to be are positive outcomes from digitalisation.
- To account for this and get closer to causation
  - Model selection into digitalisation
  - Use selection to create more fitting control groups: Propensity score matching, Propensity re-weighting (and entropy balancing).
  - Instrumental variable estimation (to be fine-tuned)
  - Event-study approach (needs follow-up)

Selection

- Recent evidence on selection: Agemoglu, Restrepo et al (2023)
- For selection of observables we follow: Koch (2021) and Guadalupe (2012).
- Selection variables: Firm size (employment), productivity (value added, value per employee, average wage), indicators of foreign trade and innovation (innovation and or capital intensity), firm age and firm sector.

Selection equation

To analyse the determinants of the digital technology adoption, we estimate the following equation.

$$DigitalAdoption_i = \psi \boldsymbol{F_{i0}} + \mu_c + \delta_s + \epsilon_i \quad (2)$$

Selection measurement is defined by data structure.

- Selection from EIBIS data. Selection on contemporenous observables. We can use panel firms that have been surveyed t-1. caveat is in the loss of sample size. Upside potential information on past digitalisation, innovation and trade controls.
- Selection from ORBIS data. Upside long lags are possible (we use 4 year lags.) Downside Orbis is selective on variables by country.

Selection equation from EIBIS panel (contemporaneous version)

VARIABLES	log lprod	log emp	wage	exporter	inno	age
l_prod	0.052***	0.042***	0.043***	0.037***	0.033***	0.034***
	(0.005)	(0.004)	(0.007)	(0.007)	(0.007)	(0.007)
l_emp		0.067***	0.067***	0.062***	0.060***	0.062***
		(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
ln_wage_avg			-0.001	-0.000	0.001	0.002
			(0.007)	(0.007)	(0.007)	(0.007)
Exporter				0.093***	0.086***	0.085***
				(0.009)	(0.010)	(0.010)
Product/Service innovator					0.134***	0.132***
					(0.013)	(0.013)
5 years to less than 10 years						-0.033
						(0.053)
10 years to less than 20 years						-0.033
						(0.052)
20 years or more						-0.060
						(0.053)
Observations	21,618	21,618	21,618	21,582	18,258	18,258
R-squared	0.070	0.108	0.108	0.114	0.117	0.118

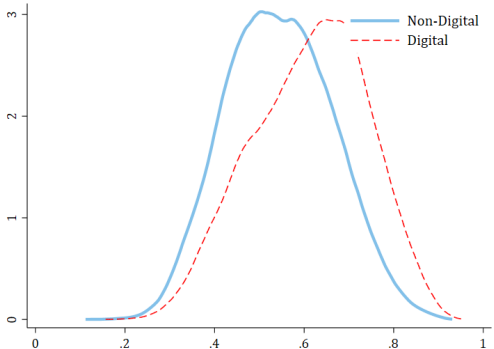
Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

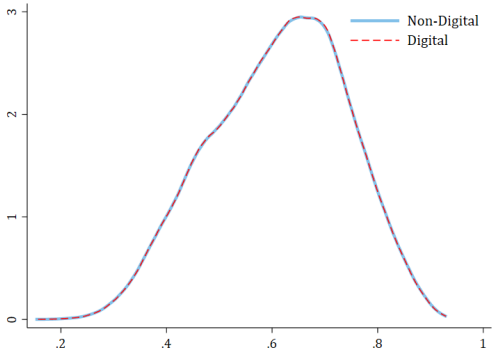
Selection equation with long lags from ORBIS

VARIABLES	log lprod	log emp	wage	exporter*	inno*	age
L4_ln_vaemp	0.058***	0.050***	0.040***	0.040***	0.032***	0.032***
	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)
L4_ln_emp		0.059***	0.057***	0.057***	0.055***	0.057***
		(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
L4_ln_avgwage			0.022*	0.022*	0.023*	0.027**
			(0.013)	(0.013)	(0.013)	(0.013)
Foreign GUO indicator				-0.020	-0.020	-0.023
				(0.032)	(0.032)	(0.032)
L4_intang_share					0.076**	0.069**
					(0.032)	(0.032)
L4_ln_capint					0.010***	0.011***
					(0.003)	(0.003)
5 years to less than 10 year						0.142
						(0.180)
10 years to less than 20 years						0.105
						(0.181)
20 years or more						0.088
						(0.180)
Observations	13,798	13,798	13,668	13,668	13,399	13,399
R-squared	0.079	0.107	0.106	0.106	0.107	0.108

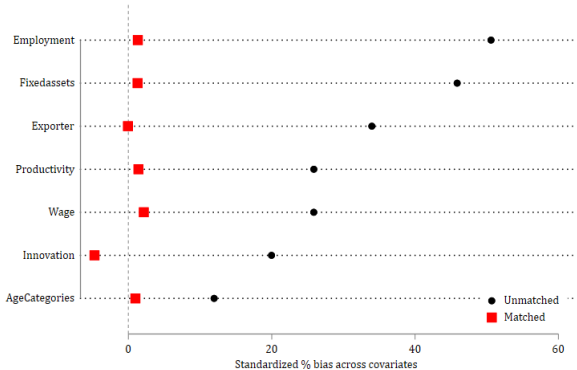
Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Propensity - before and after





Reduction of bias after propensity score matching (EIBIS)



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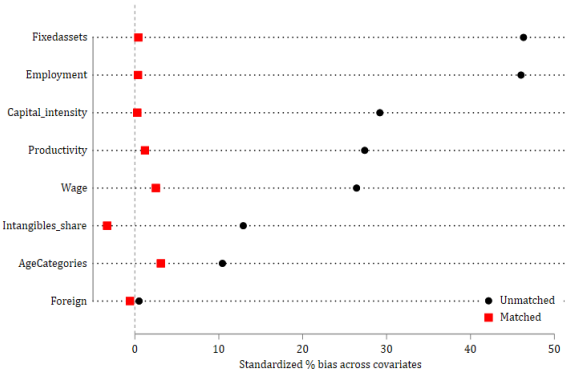

Propensity score matching: Selection on Survey

Dependent: variable	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
Digital	0.268***	0.409***	0.299***	0.042***	0.036**	0.019	0.024*
	(0.029)	(0.025)	(0.034)	(0.007)	(0.015)	(0.014)	(0.013)
Observations	17,649	18,539	16,958	16,959	17,467	17,148	18,447
R-squared				0.057	0.354	0.447	0.432
Pseudo R2	0.101	0.158	0.0603				

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Propensity score matching: Selection on ORBIS

Dependent: variable	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
digital	0.277***	0.415***	0.323***	0.044***	0.032**	0.010	0.018
	(0.019)	(0.018)	(0.023)	(0.004)	(0.013)	(0.013)	(0.011)
Sample size	32,241	35,681	30,735	30,738	31,959	30,934	34,387
R^2				0.061	0.336	0.419	0.385
Pseudo R^2	0.0943	0.148	0.0625				

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Propensity re weighting: Selection on Survey

Dependent: variable	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
Digital	0.279***	0.411***	0.319***	0.048***	0.045***	0.024*	0.038***
	(0.025)	(0.020)	(0.028)	(0.005)	(0.013)	(0.013)	(0.012)
Observations	29,426	31,054	28,437	28,437	29,005	28,481	30,841
R-squared				0.074	0.374	0.441	0.442
Pseudo R2	0.0943	0.156	0.0664				

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

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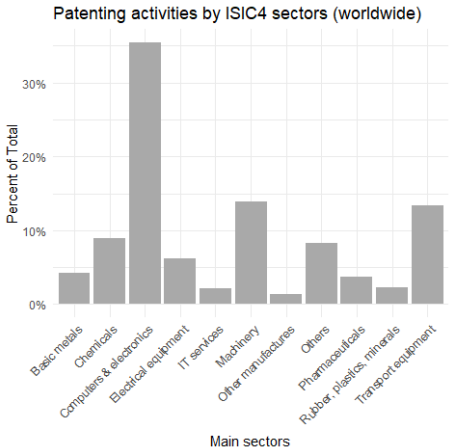
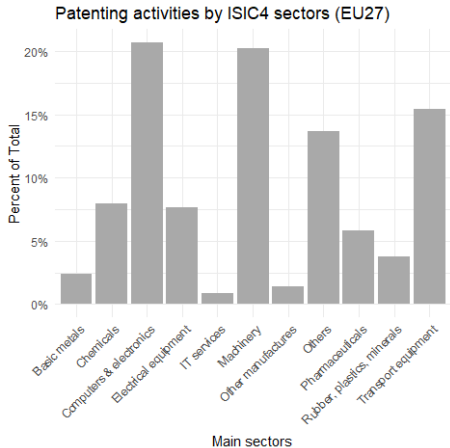
Can we use instruments?

- We need variable Z to influence / affect the adoption decision of a specific firm in a given industry but that do not directly affect the firm outcome.
- We thought of the digital innovation intensity the industry frontier.
- We rely on OECD-JRC top R&D Investor patent portfolio database.
- We rely on Figaro input output matrices to link innovation to local sector.
  - Demonstration effect via own industry
  - Spillover via industry linkages

Patents in the World Corporate Top R&D Investors IP database

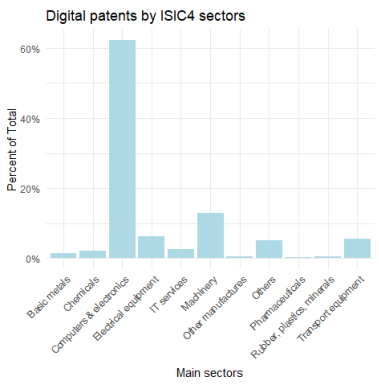


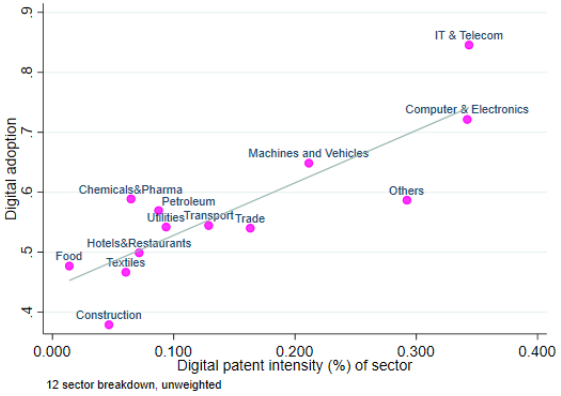


Patent Classification to Digital

EUROSTAT Digital indicators (IPC codes)	
G06C	Digital computers in which all the computation is effected mechanically
G06D	Digit fluid-pressure computing devices
G06E	Optical computing devices
G06Q 30- 99/00	Commerce, e.g. marketing, shopping, billing, auctions or e-commerce, ..
G06Q 20/00	Payment schemes, architectures or protocols
...	
OECD: Baruffaldi et al 2022. (IPC code)	
G06K9/00	Methods for reading or recognising printed or written characters or for recognising patterns..
G06K9/62	Methods or arrangements for recognition using electronic means
G06T7/00	Image data processing or generation, in genera
...	
G06F17/27	Automatic analysis, e.g. parsing, orthograph correction...
H04N5/232	Remote control for television camera

Digital patents in the World Corporate Top R&D Investors IP database





To construct the share terms of our instrument, we gather Input-Output table (2017) from Eurostat. We calculated upstream and downstream output-input coefficients as shares. For each country-sector of origin (c_o and s_o), we calculated the upstream and downstream shares using sector of destination, s_d.

$$Upstream(Downstream)Share_{c_o,s_o,s_d} = \frac{M_{c_o,s_o,s_d}}{\sum_{s_d} M_{c_o,s_o,s_d}}$$

where M_{c_o,s_o,s_d} refers to the output levels. Sectors in the instrument construction part refers to the CPA categories. Alternatively, $\frac{M_{c_o,s_o,s_d}}{\sum_{s_d} M_{c_o,s_o,s_d}}$ the shares represent the input required to produce one unit of production of country-industry c_o and s_o from industry s_d.

IV - digital patents of upstream and downstream sectors as instrument

Instrumental variable estimation

Dependent variable:	Training	Management practices	Innovation (binary)	Innovation (share)	ln(VA/emp)	ln(TFP)	ln(wage/emp)
Digital	0.680***	0.241*	0.456***	0.369***	1.487***	1.718***	1.698***
	(0.161)	(0.140)	(0.153)	(0.092)	(0.411)	(0.417)	(0.351)
Sample size	38,066	41,529	35,135	35,135	36,058	34,617	39,275
First-stage							
Digital patents *in*							
upstream sectors	0.029***	0.025***	0.020***	0.020***	0.024***	0.025***	0.023***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
downstream	0.025***	0.024***	0.028***	0.028***	0.022***	0.021***	0.023***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
F-test statistic	57.3	50.2	45.2	45.2	38.4	37.4	43.6

Note: All regressions control for status, age and size categories, country, industry and year. Standard errors clustered by country and industry) in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

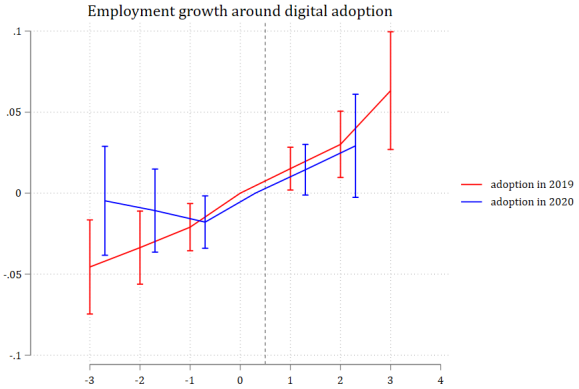
How does digitisation effect employment?

- Self declaration approach.
- Event-study approach.

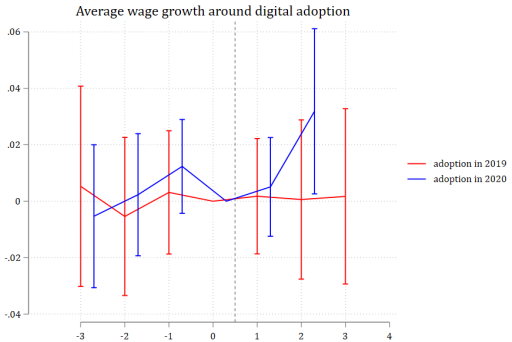
Multinomial logit: Self reported dynamics for the next 3 years

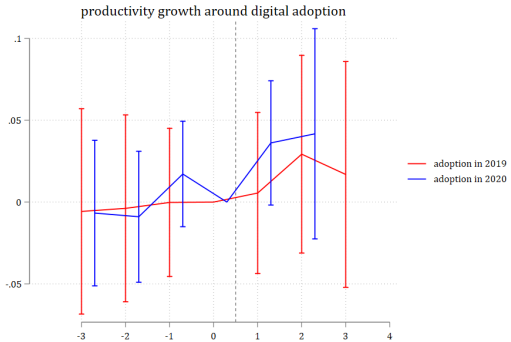
	Decrease	Increase
Construction	-1.369***	-0.0415
Services	-0.580***	-0.0239
Infrastructure	-0.630***	0.306***
Small	0.530***	0.121***
Medium	1.075***	-0.191***
Large	1.506***	-0.210***
2 years to less than 5 years	0.218	0.834***
5 years to less than 10 years	0.172	0.724**
10 years to less than 20 years	0.021	0.514*
20 years or more	0.301	0.194
Average Wage (logs)	-0.0033	0.0626***
Labour Productivity (logs)	-0.0612**	0.0658***

Event Study: Single technology adopters



Event Study: Single technology adopters





Conclusion

- We present novel evidence that firms using digital technologies perform better
  - advanced digital technologies (ADT): 3D printing, advanced robotics, drones, augmented or virtual reality, digital platforms, IoT, big data analytics and AI
  - firm performance outcomes: investment in employee training, management practices, innovation, firm productivity
  - with data from the EIB Investment Survey (EIBIS) on 27 EU countries
  - in line with recent results in the literature (Acemoglu et al., 2022)
- Policies aimed at increasing firm performance and managing the employment effects of digital adoption should consider the impact of upstream and downstream partners as well as the firm itself

Thank you!

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Additional slides

The EIB Investment Survey (EIBIS)

Definition of outcome variables (1/2)

- Innovation: What proportion of the total investment in (t-1) year was for
  - (A) Developing or introducing new products, processes or services?
  - (B) Replacing capacity?
  - (C) Expanding existing capacity?

- Training: How much did your business invest in each of the following with the intention of maintaining or increasing your company's future earnings?

- Management practices: Did your company use a formal strategic business monitoring system (that compares the firm's current performance against a series of strategic key performance indicators)?

Definition of outcome variables (2/2)

- Wage / Employment
  - How much did the company spend on wages in (t-1) financial year? We are referring here to gross wages, including all benefits and benefits in kind (i.e. including various types of non-wage compensation provided to employees in addition to their normal wages or salaries). Expressed in Euros.
  - How many people does your company employ either full or part time at all its locations including yourself? (Please include freelancers working regularly for your company. Full-time and part-time employees should each count as one employee. Employees working less than 12 hours per week should be excluded.)
- Labour productivity: log of value added over employment
- TFP: log of residuals from OLS regression of $VA = F(K, L)$

EIBIS - matched to Orbis

- An enterprise is defined as a company trading as its own legal entity: branches excluded from the target population
  - but definition broader than a typical enterprise survey, given that some company subsidiaries are their own legal entities
- Minimum number of employees is 5
  - with full-time and part-time employees being counted as one employee, and employees working less than 12 hours per week excluded
- ORBIS dataset of Bureau van Dijk used as the sampling frame
  - EIBIS matched to data on balance sheet and profit and loss statements
  - match done for each firm by Ipsos MORI, which then sends anonymised data to EIB
  - the EIB does not have the name, address, contact details or any additional
  - individual information that could identify the firms surveyed in EIBIS

EIBIS - Representativeness

- Brutscher, Coali, Delanote and Harasztosi (2020): evidence on representativeness of EIBIS for the business population of interest
  - comparison with the population of firm-level data in Eurostat SBS (e.g. average firm size, labour productivity, etc.)
  - comparisons with CompNet (extracted from confidential firm-level datasets available within National Central Banks or National Statistical Institutes)
  - comparisons with random samples from ORBIS (e.g. sales growth, cash flow ratio, leverage, returns on assets, etc.)

Orbis

- ORBIS is a popular source of administrative data for cross-country analyses at the firm level
  - majority of information comes from business registers collected by local chambers of commerce to fulfil legal and administrative requirements
  - Bureau van Dijk organises the data and arranges them in a standard "global" format to facilitate company comparisons across countries
  - Kalemli-Ozcan et al. (2015) and Bajgar et al. (2020): discussion of the (dis)advantages of using ORBIS for economic analysis of firm dynamics