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Digital technology adoption, productivity gains in adopting firms and sectoral spill-overs: Firm-level evidence from Estonia

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DIGITAL TECHNOLOGY ADOPTION, PRODUCTIVITY GAINS IN ADOPTING FIRMS AND SECTORAL SPILL-OVERS – FIRM-LEVEL EVIDENCE FROM ESTONIA

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Abstract / Resumé

Digital technology adoption, productivity gains in adopting firms and sectoral spill-overs – Firm-level evidence from Estonia

With a newly constructed firm-level dataset combining various survey- and registry data from Statistics Estonia, this paper sheds new light on the labour productivity premium from adopting digital technologies and boosting digital skill use. The productivity premium is decomposed into a direct effect benefitting the firms actually increasing their digital intensity, and an indirect effect of belonging to a sector with high digital intensity. The firm-level productivity premium of being an adopting firm is consistently positive and sizeable across different digital technologies and measures of skill intensity. The evidence also suggests positive spill-over effects in manufacturing sectors and sectors with a high routine task content and thus a high automation potential.

This Working Paper relates to the 2019 OECD Economic Survey of Estonia

http://www.oecd.org/economy/estonia-economic-snapshot/

Keywords: Digitalisation, productivity, skills, training.

JEL classification codes: D24, E22, J24, M53, O33.

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Adoption de la technologie numérique, gains de productivité dans l'adoption d'entreprises et externalités sectorielles - Données au niveau des entreprises d'Estonie

Avec une base de données nouvellement construite au niveau de l'entreprise combinant diverses données d'enquêtes et de registres de Statistics Estonia, ce document jette un nouvel éclairage sur la prime de productivité du travail liée à l'adoption des technologies numériques et à l'augmentation de l'utilisation des compétences numériques. La prime de productivité se décompose en un effet direct bénéficiant aux entreprises augmentant effectivement leur intensité numérique et en un effet indirect d'appartenance à un secteur à forte intensité numérique. La prime de productivité au niveau de l'entreprise en tant qu'entreprise adoptive est toujours positive et appréciable pour différentes technologies numériques et mesures de l'intensité des compétences. Les preuves suggèrent également des retombées positives dans les secteurs manufacturiers et les secteurs avec un contenu de tâches routinières élevé et donc un potentiel d'automatisation élevé.

Ce document de travail est lié à l'Étude économique de l'OCDE de 2019 consacrée à l’Estonie.

http://www.oecd.org/fr/economie/estonie-en-un-coup-d-oeil/

Mots clés: digitalisation, productivité, compétences, formation.

Codes JEL: D24, E22, J24, M53, O33.

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Digital technology adoption, productivity gains in adopting firms and sectoral spill-overs – Firm-level evidence from Estonia

By: Natia Mosiashvili and Jon Pareliussen[1]

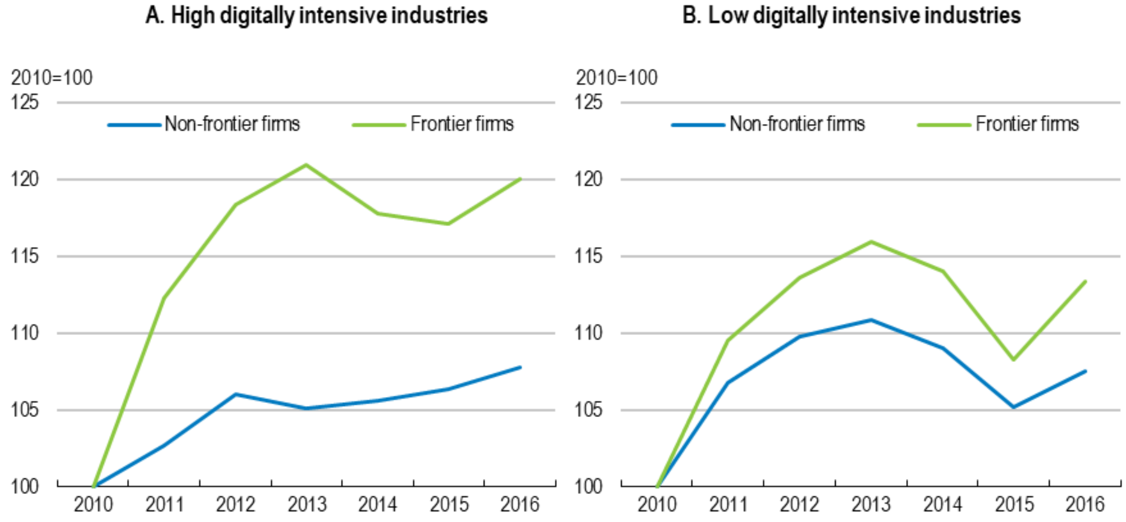
Introduction

1. Digital technologies change the fabric of our economies. Governments have new ways to interact with and provide services to citizens and firms. Firms have new tools to design, produce and market goods and services, and to interact with other firms, workers, consumers and governments. Individuals have new tools for social and economic interactions. Technologies such as cloud computing, software to automate supplier- and customer relations, online platforms and artificial intelligence seem to offer a vast potential to boost productivity and living standards, but aggregate productivity growth has on the contrary declined sharply across the OECD the past decades. Estonia is no exception. Labour productivity growth was impressive from the 1990s, following the collapse of the Soviet Union, but has slowed since the Global Financial Crisis (OECD, 2019a; *OECD Economic Survey of Estonia*, 2019).

2. The productivity slowdown across the OECD has multiple and partly interlinked reasons, some cyclical and related to the legacy of the global financial crisis, for example that spare capacity and difficult access to finance have held back investments in tangible and intangible capital in some countries and industries. However, productivity growth started slowing down before the crisis in most OECD countries and remains weak to date, suggesting an important role for structural factors (OECD, 2019a). Previous OECD research indicates that productivity performance of the best performing firms ("the productivity frontier") has continued to grow at least as fast as before, while the divergence between the frontier and the rest has increased, holding back aggregate productivity (Andrews *et al.*, 2016). This pattern also holds for Estonia, and divergence is particularly strong in digitally intensive industries (Figure 1).

[1] The authors, both working in the OECD Economics Department, would like to thank Christina Von Rueden, Dirk Pilat, Margit Molnar and Patrick Lenain for valuable comments and suggestions at various stages of the preparation of this paper. Special thanks go to Kadri Männasoo for great comments and support and Karsten Staehr for organising a seminar at the Tallinn University of Technology. A draft of the paper was also presented to the OECD Economic and Development Review Committee. Thanks to Damien Azzopardi for statistical support, Stephanie Henry and Heloise Wickramanaya for secretarial assistance.

Figure 1. Labour productivity at the frontier and for the average non-frontier firm



Note: The figure is calculated as unweighted averages over the full population of Estonian firms in an unbalanced panel of 110,316 unique firms and 425,912 observations. “Frontier firms” is measured by the average of log labour productivity for the top 5% of companies with the highest productivity levels in each 2-digit industry and year. The “Non-frontier firms” lines capture the averages of the log-productivity distribution in each industry and year (excluding the top 5%). The values obtained for the detailed 2-digit industries are averaged to industry groups that are classified either as having “high” or “low” digital intensities according to the methodology in Calvino et al. (2018).
Source: Author’s calculations based on Statistics Estonia annual bookkeeping reports database.

3. Recent OECD work argues that the current wave of digitalisation has supported productivity growth, but not sufficiently to offset the cyclical and structural headwinds to productivity mentioned above. The same research points to a vast potential to use digital technologies to boost productivity further, notably by moving digital adoption rates in laggard firms closer to those of frontier firms. For example, increasing the sector-level adoption rate of Customer Relationship Management (CRM) front-office software by 10 percentage points is estimated to increase multifactor productivity (MFP) by 1.7% in the average EU firm over a three-year horizon. Cloud computing and Enterprise Resource Planning (ERP) back-office software both adds an average of approximately 1% (OECD, 2019a; Gal *et al.*, 2019). Furthermore, digital technologies are complementary to each other. Cross-country estimates indicate that boosting high-speed Internet connections (30Mbit/s) by 10% would boost productivity directly by 2% in Estonia over a three-year horizon, while indirect effects from increased adoption of cloud computing, ERP and CRM would add another 1.5% to the productivity increase (Sorbe, *et al.*, 2019). Complementarities with other firm assets, such as skills and organisational practices, are illustrated by the finding that those firms which were most productive in the outset were also those gaining the most from adopting new digital tools (Gal *et al.*, 2019).

4. The aim of this paper is to estimate the productivity potential of adopting digital technologies at the firm- and sector- level in Estonia. The analysis builds on and extends recent OECD work, notably Gal *et al.* (2019) and Sorbe *et al.* (2019). It rests on a newly constructed firm-level dataset combining various survey- and registry data from Statistics Estonia. The paper distinguishes between direct productivity effects to firms adopting digital technologies or boosting digital skill use, and spill-overs benefitting all (including non-adopting) firms according to the digital technology adoption rates and digital skill use intensity in their respective sectors. This decomposition is only possible with firm-level data on digital technology and skill use, and to the best of our knowledge this is the first study quantifying such effects. Reasons for such spill-overs are not explored, but could for example include value chain participation or knowledge spill-overs.

5. The firm-level productivity growth premium of being a sectoral frontrunner in digital adoption is consistently positive across different digital technologies. Private returns to digitalisation is found to be higher in services sectors than in manufacturing. The evidence also suggests that firms draw sizeable and statistically significant benefit from a higher level of digitalisation at the sector level, but concentrated to manufacturing sectors and sectors with a high routine task content, and thus a high automation potential. Higher social than private returns may lead to underinvestment in digitalisation, notably in manufacturing.

6. The remainder of the paper is structured as follows: The next section describes the data and the chosen methodology, adapted from Gal *et al.* (2019) and Bell and Jones (2015). The third section presents empirical results and discusses economic significance of the findings. The fourth and final section summarises, discusses and concludes.

Methodology and data

7. Following Bourlès *et al.* (2010), the empirical specification takes a neo-Schumpeterian growth approach, a workhorse model in productivity research since Aghion and Howitt (1997). Labour productivity for a given non-frontier firm *i,* in sector *s* at time *t* ($LP_{is,t}$) is modelled as an auto-regressive distributed lag ADL(1,1) process in which the (log) level of *LP* is co-integrated with the (log) level of *LP* at the sector frontier:

$$lnLP_{is,t} = \alpha_0 lnLP_{is,t-1} + \alpha_1 lnLP_{Fs,t} + \alpha_2 lnLP_{Fs,t-1} + \alpha_3 X_{is,t} + \gamma_s + \tau_t + \varepsilon_{is,t} \quad (1)$$

where $lnLP_{Fs,t}$is the labour productivity level at the productivity frontier *F*, defined as the 5% most productive firms in each sector (*s*) - time (*t*) cell of the sample. $X_{is,t}$ is a vector of firm-level control variables, including variables measuring digital adoption and digital skill use. γ_s and γ_t are sector and time fixed effects, respectively, and $\varepsilon_{is,t}$ is a random error term. Under the assumption of long-run homogeneity (α_0+ α_1+ α_2 = 1), the ADL(1,1) process in equation (1) has the following Error Correction Model (ECM) representation:

$$\Delta lnLP_{is,t} = \alpha_1 \Delta lnLP_{Fs,t} + (1-\alpha_0) gap_{is,t-1} + \alpha_3 X_{is,t} + \gamma_s + \tau_t + \varepsilon_{is,t} \quad , \quad (2)$$

$$\text{where } gap_{is,t-1} = lnLP_{Fs,t-1} - lnLP_{is,t-1}$$

8. Equation (2) has good statistical properties and is used as the main specification in this paper with some variations, as outlined below. It implies that productivity growth depends on productivity growth at the frontier, and the distance between firm *i*'s productivity and the frontier.

9. Productivity levels and growth rates differ for firm-specific reasons, and for reasons common to firms within each respective sector. For example, capital inputs per worker and the level of use of individual digital technologies differ systematically from sector to sector. It is also possible that inputs in one firm affects not only this firm's productivity, but create spill-overs affecting the productivity of other firms in the sector. The inclusion of sector fixed effects in the above regression set-up isolates the firm-specific deviations from the sector average, but does not reveal anything about such potential sectoral spill-overs. Attempting to overcome this limitation, control variables, including the digital adoption and skill use variables, are decomposed into sector averages, $\bar{X}_{s,t}$, and deviations from their sector averages ($X_{is,t} - \bar{X}_{s,t}$) using the following identity:

$$X_{is,t} = \left(X_{is,t} - \bar{X}_{s,t}\right) + \bar{X}_{s,t} \quad (3)$$

Inserting (3) into (2), and removing sector fixed effects yields the following equation:

$$\Delta lnLP_{is,t} = \alpha_1 \Delta lnLP_{Fs,t} + (1-\alpha_0) gap_{is,t-1} + \alpha_3 \left(X_{is,t} - \bar{X}_{s,t}\right) + \alpha_4 \bar{X}_{s,t} + \gamma_t + \varepsilon_{is,t} \quad (4)$$

10. Re-defining firm-level variables into deviations from their sector averages ($X_{is,t} - \bar{X}_{s,t}$), excluding frontier firms, does not affect variance, and has therefore no impact on the regression coefficient, α_3, all else equal. Sector fixed effects are replaced by sector averages, $\bar{X}_{s,t}$. In this set-up α_3 represents firm

("within") effects, while α_4 represents sector ("between") effects. A useful reference for this decomposition is Bell and Jones (2015), who propose this methodology to eliminate time fixed effects of a panel regression in what they name a "within-between random effects" panel regression set-up. The sector average variables will not capture sector differences as efficiently as sector fixed effects, and this may affect firm-level coefficient estimates, as discussed below.

11. Variables, sourced mostly from Statistical Estonia, are presented in Table 1, and descriptive statistics in Table 2. The dataset is built around a sample of 3400 companies participating in the Community Survey on ICT Usage and e-commerce in Enterprises in 2016, out of a total target population of 6600 firms with 10 or more employees located in Estonia. After data cleaning and exclusion of agriculture, fishery, finance and public sectors, the dataset contains 2725 firms. Target respondents are decision makers with major responsibility for ICT-related issues in the enterprise, or someone at the managing director level or the owner in the case of smaller enterprises. Enterprises with 50 or more persons employed are fully covered by the sample, while stratified sampling by economic activity is used for enterprises with 10–49 employees[2]. Sample weights provided by Statistics Estonia are applied in the regressions throughout this paper[3]. This sample is supplemented with data from various registries maintained by Statistics Estonia and the OECD Survey of Adult Skills, as specified in Table 1. Limiting the dataset to firms with 10 or more employees is necessary to control for digital intensity. However, it has some drawbacks, notably that a large majority of firms in Estonia, as in all OECD countries, have less than 10 employees, and that a number of these firms belong to the productivity frontier.

12. Shifting the productivity frontier of the sector outwards is expected to raise productivity growth in other firms in the sector with a factor between zero and one, as innovation at the frontier benefits other firms, but only partially. Frontier firms are excluded from the regression sample to avoid endogeneity issues. Assuming convergence, the lagged gap to the frontier should also have a positive coefficient, as a larger gap would imply a higher potential to improve efficiency and catch up with firms at the frontier. Divergence is also possible if laggard firms see access to production factors decrease, for example if they lose attractiveness as employers and thus fail to attract the skills needed to realise the potential offered by new technologies.

13. The chosen dependent variable is labour productivity growth, as it is straightforward to calculate and avoids methodological issues associated with calculating multifactor productivity at the firm level. Correlations between labour productivity and multifactor productivity are usually high (Gal, 2013). This choice makes it appropriate to control for investments, which is done by introducing the change of the natural logarithm of non-current assets, a variable expected to have a positive sign. Further firm-level controls include age, size, and whether or not the firm is and exporter. These, and the gap to the frontier, are sourced from registry data and hence available as a time series.

[2] See Statistics Estonia for further details: https://www.stat.ee/esms-metadata?code=20505 (Accessed 31 October 2019).

[3] 2016 weights are applied for all years.

Table 1. Description of variables

	Description	Level	Coverage	Source
	Dependent variable			
Labour productivity growth	The change of the natural logarithm of labour productivity calculated as revenue divided by the labour input.	Enterprise	2011-2016	Annual bookkeeping report (Statistics Estonia).
	Control variables			
Frontier growth	Average growth of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell.	Sector	2011-2016	Annual bookkeeping report (Statistics Estonia).
Gap to frontier	Lagged distance to the frontier.	Enterprise	2011-2016	Annual bookkeeping report (Statistics Estonia).
Investments	The growth of the natural logarithm of non-current assets.	Enterprise	2011-2016	
Firm age	Firm age calculated as the difference between the current year and the year of registration.	Enterprise	2011-2016	Statistical Register of Economic Units (Statistics Estonia).
Exporter dummy	Dummy for the enterprises that have exported a good or a service in respective year.	Enterprise	2011-2016	Trade in Goods and Services (Statistics Estonia).
Firm size	Firm size computed by the number of employees as micro (1-9 employees), small (10-49 employees), medium (50-249 employees), and large (250+ employees) enterprises.	Enterprise	2011-2016	Statistical Register of Economic Units (Statistics Estonia).
	Digital variables			
High-speed broadband	The maximum contracted download speed of the fastest internet connection is at least 30 Mb/s.	Enterprise	2016	Community Survey on ICT Usage and e-commerce in Enterprises (Statistics Estonia).
ERP	Enterprises who have ERP software package to share information between different functional areas.	Enterprise	2016	Community Survey on ICT Usage and e-commerce in Enterprises (Statistics Estonia).
CRM	Enterprises using software solutions like Customer Relationship Management.	Enterprise	2016	Community Survey on ICT Usage and e-commerce in Enterprises (Statistics Estonia).
Digital skill use at work	Share of employees that use computers for business purposes.	Enterprise	2016	Community Survey on ICT Usage and e-commerce in Enterprises (Statistics Estonia).
ICT training dummy	The firm has provided ICT training for its employees.	Enterprise	2016	
	Sector-level control variables			
Manufacturing/ services dummies	Dummy indicators of firms belonging to manufacturing (NACE Rev.2 10-33) or services (NACE Rev.2 45-82).	Sector	2016	Community Survey on ICT Usage and e-commerce in Enterprises (Statistics Estonia).
Routine Intensity	The extent to which workers can modify the sequence of their tasks and decide the type of tasks to be performed on the job.	Sector	2012	OECD Programme for the International Assessment of Adult Competencies (PIAAC)

14. The coefficient capturing the productivity effect of firm-level digital technology adoption and digital skill use in the respective regressions is the main variable of interest. These variables are only available for one year in the dataset, and like in Gal *et al.* (2019) they are assumed to be constant over the estimation period. The different digital variables are correlated, so they are estimated in separate regressions. Results are hence not cumulative for the various digital variables. The technologies included are high-speed broadband internet connection (above 30Mbit/s), enterprise resource planning software (ERP) and customer relationship software (CRM). Separate regressions are also included for the share of employees using computers for business purposes and the dummy variable for companies providing ICT training. The

share of employees using computers for work purposes is a broader measure than the other variables, likely capturing better the overall level of firms' digitalisation.

Table 2. Descriptive statistics

	Mean	Median	Bottom decile	Top decile	Standard deviation	Observations
Dependent variable						
Labour productivity growth (log)	0.02	0.03	-0.27	0.30	0.33	12821
Firm-level control variables						
Frontier growth (log)	0.03	0.03	-0.12	0.21	0.21	13075
Gap to frontier (log)	2.26	2.12	1.19	3.53	0.92	12594
Investments (log)	0.10	0.07	-0.29	0.48	0.48	11071
Firm age	14.07	15.00	4.00	22.00	6.67	13470
Exporter dummy	0.54	1.00	0.00	1.00	0.50	13470
Firm size	2.34	2.00	2.00	3.00	0.70	13470
Digital variables						
high-speed broadband dummy	0.53	1.00	0.00	1.00	0.50	2725
ERP dummy	0.33	0.00	0.00	1.00	0.47	2725
CRM dummy	0.30	0.00	0.00	1.00	0.46	2725
Digital skill use at work	0.50	0.38	0.11	1.00	0.36	2725
ICT training dummy	0.19	0.00	0.00	1.00	0.39	2660
Variables for additional analyses						
Services sector dummy	0.62	1.00	0.00	1.00	0.49	13470
Manufacturing sector dummy	0.28	0.00	0.00	1.00	0.45	13470
Routine intensity indicator	3.65	3.60	3.19	4.10	0.32	2527

Note: See Table 1 for a detailed description of variables.

15. The typical firm's motive for adopting digital tools and investing in digital skills is an expectation that it will increase the efficiency of production and internal processes. This is an economic argument for a causal link between the digital variable and the dependent variable. However, there is a potential endogeneity issue if firms with higher productivity growth for reasons not related to digital adoption also are more inclined to adopt digital technologies. For example, firms with efficient organisation and management practices may have more resources to invest, and may find it easier to integrate and adapt processes with digital tools. This potential endogeneity calls for caution when interpreting the results presented below.

16. In line with previous literature (eee for example Andrews *et al.,* 2016 or Gal *et al.*, 2019), economic sectors are defined according to NACE Rev 2, excluding agriculture, forestry and fishing, financial and insurance activities and "other services". Public sectors, including public administration, defence, education, human health and social work activities are also excluded. Dummy indicators of firms belonging to manufacturing (NACE Rev.2 10-33) or services (NACE Rev.2 45-82) are created and interacted with the technology adoption and skill use variables for additional analyses into differences in the productivity effect of digitalisation between sectors. Likewise, a sector-level variable of routine content is constructed following Marcolin *et al.* (2016), derived from the OECD Survey of Adult Skills (PIAAC). This variable measures the extent to which workers can modify the sequence of their tasks and decide the type of tasks to be performed on the job, and is thus an indicator of the potential for automation. This variable is interacted with the digital variables as outlined below.

Results

Main specification

17. Results from the empirical specification in Equation (2) above, using an OLS estimator, are presented in Table 3. All digital technologies and skill use variables are significant at the 99% level,

indicating a robust link between digital technology adoption, digital skill use and productivity. The validity of the results is underlined by well-behaved results where the main control variables have the expected sign and are in general highly significant. Frontier growth raises overall productivity by a factor below one, as expected, significant at the 99% level. Likewise, the lagged productivity gap to the frontier is associated with higher productivity growth in the present, significant at the 99% level. This indicates that laggings firms do catch up more quickly to the frontier on average, even though not fast enough to offset divergence between the frontier and the rest. Investments, measured as the difference in the logarithm of non-current assets, also has the expected sign, significant at the 99% level. The exporter dummy is positive and significant in line with previous results (Benkovskis *et al.,* 2017). Firm age is positively and significantly correlated with productivity growth, while there is no statistically significant association with firm size.

Table 3. Regression results, main specification

Dependent variable: Annual labour productivity growth

VARIABLES	Broadband (>30Mbit/s)	ERP	CRM	Computer use share	ICT training
Frontier growth	0.209***	0.206***	0.208***	0.227***	0.209***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Time lagged gap to the frontier	0.125***	0.124***	0.125***	0.136***	0.124***
	(0.012)	(0.011)	(0.011)	(0.012)	(0.011)
Investment	0.037***	0.037***	0.037***	0.035***	0.037***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Firm age	0.001**	0.002**	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exporter dummy	0.068***	0.068***	0.067***	0.061***	0.067***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Firm size 50-249 employees	-0.004	-0.004	-0.003	0.003	-0.008
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Firm size 250 and more employees	-0.001	-0.002	0.001	0.015	-0.014
	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)
Digital variable	0.029***	0.038***	0.045***	0.144***	0.050***
	(0.008)	(0.010)	(0.009)	(0.017)	(0.010)
Constant	-0.299***	-0.301***	-0.297***	-0.349***	-0.289***
	(0.035)	(0.034)	(0.034)	(0.036)	(0.033)
Observations	10,368	10,368	10,368	10,191	10,368
R-squared	0.085	0.086	0.086	0.098	0.085

Note: This table reports results of an OLS regression as specified in equation (2) of this paper. Firm-level change of the natural logarithm of labour productivity is regressed on average change of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell, the firm's lagged gap to the productivity frontier, the change of the natural logarithm of the firm's non-current assets, firm age, a firm-level exporter dummy, firm size, the average age of employees in the firm, firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and the provision of ICT training to its employees, as well as the share of employees using computers for work purposes. All regressions include sector- and year fixed effects, and standard errors are clustered at the firm level. Firms at the sector-level productivity frontier are excluded from the regressions. Regressions are based on firm-level data from Estonia in 22 sectors (NACE Rev 2, 10-82) over the period 2011-2016 for firms with 10 or more employees. To maximise coverage, averages of each digital variable are used over the period 2011-2016. Standard errors are in parentheses, ***, ** and * represent p<0.01, p<0.05 and p<0.1, respectively. Main results are highlighted.
Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education databases (all provided by Statistics Estonia).

Sector spill-overs

18. Results from the empirical specification in Equation (4), where sector fixed effects are replaced by sector averages are presented in Table 4. As in the main specification, the firm-level (within) effects of digital technologies and skill use variables are positive and significant at the 99% level, although with lower

coefficient estimates. All firm-level effects for the other control variables also keep the same sign and same magnitudes relative to each other as in the main specification, and those significant in the main specification remain significant at the 99% level, indicating that the empirical strategy of replacing sector fixed effects with sector averages of the control variables is fairly successfully.

19. However, sector (between) effects of the digital variables, which can be interpreted as the additional firm-level productivity growth from belonging to a sector with high digital intensity, are insignificant except for high-speed broadband, and ICT training, both significant at the 95% level. Other sector-level effects are mostly insignificant, with the exception of firm age, which is negative and significant, contrasting a positive firm-level effect. This could reflect imperfect competition in some sectors holding back business dynamics, and thus reducing productivity growth while increasing the average age of firms in these sectors. Within sectors, older firms have proven their ability to perform time and again and thus tend to be more productive.

Table 4. Regression results, sector spill-overs

VARIABLES	Broadband (>30Mbit/s)	ERP	CRM	Computer use share	ICT training
Frontier growth	0.162***	0.163***	0.164***	0.174***	0.162***
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Time lagged gap to the frontier	0.080***	0.081***	0.082***	0.086***	0.080***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Investment	0.032***	0.032***	0.032***	0.030***	0.032***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)
Firm age (within)	0.002**	0.002**	0.002**	0.002**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Firm age (between)	-0.007***	-0.008***	-0.008***	-0.009***	-0.007***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Exporter (within)	0.044***	0.044***	0.044***	0.036***	0.044***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Exporter (between)	0.019	0.015	0.029*	0.029*	0.020
	(0.016)	(0.018)	(0.016)	(0.016)	(0.017)
Firm size 50-249 employees	0.006	0.004	0.006	0.010	0.003
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Firm size 250 and more employees	0.010	0.005	0.009	0.019	-0.001
	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)
Digital variable (within)	0.014*	0.027***	0.033***	0.113***	0.032***
	(0.008)	(0.009)	(0.009)	(0.016)	(0.009)
Digital variable (between)	0.074**	0.072	-0.034	-0.000	0.065**
	(0.031)	(0.047)	(0.037)	(0.017)	(0.032)
Constant	-0.114***	-0.081***	-0.057*	-0.071**	-0.078**
	(0.038)	(0.031)	(0.031)	(0.032)	(0.031)
Observations	10,368	10,368	10,368	10,191	10,368
R-squared	0.058	0.059	0.059	0.066	0.058

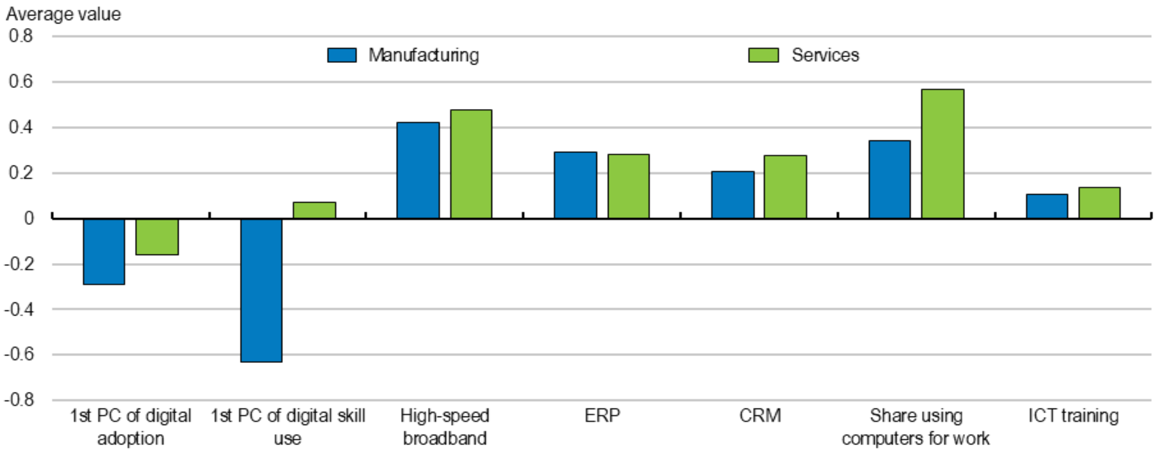
Note: This table reports results of an OLS regression as specified in equation (4) of this paper. Firm-level change of the natural logarithm of labour productivity is regressed on average change of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell, the firm's lagged gap to the productivity frontier, the change of the natural logarithm of the firm's non-current assets, firm age, a firm-level exporter dummy, firm size, the average age of employees in the firm, firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and the provision of ICT training to its employees, as well as the share of employees using computers for work purposes. Sector average variables are denoted "between", while firm-level differences to their respective sector averages are denoted "within". All regressions include year fixed effects, and standard errors are clustered at the firm level. Firms at the sector-level productivity frontier are excluded from the regressions. Regressions are based on firm-level data from Estonia in 22 sectors (NACE Rev 2, 10-82) over the period 2011-2016 for firms with 10 or more employees. To maximise coverage, averages of each digital variable are used over the period 2011-2016. Standard errors are in parentheses, ***, ** and * represent p<0.01, p<0.05 and p<0.1, respectively. Main results are highlighted.

Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education databases (all provided by Statistics Estonia).

Manufacturing versus services

20. Gal et al. (2019) find that digital adoption is higher in services sectors (NACE Rev.2 45-82) than in manufacturing (NACE Rev.2 10-33), while the association between digital take-up and productivity at the sector level is stronger in manufacturing for most technologies except the take-up of high-speed broadband. Doing the same sectoral split, digital adoption is found to be more widespread in services sectors also in Estonia (Figure 2). However, interacting these dummies with the digital variables and inserting in Equation (2) yields somewhat stronger firm-level productivity effects from higher digital technology and skill-use intensity in services than manufacturing (Table 5). This result is consistent with overall higher digital adoption in services than in manufacturing, since higher returns incentivises investments in digitalisation.

Figure 2. Digital adoption and skill use by broad sector (2016)



Note: Estonian firms with 10 or more employees. Service sectors are defined as NACE Rev.2 45-82), manufacturing as NACE Rev.2 10-33.
Source: Authors' calculations based data from the Community Survey on ICT Usage and e-commerce in Enterprises.

Table 5. Regression results, manufacturing vs services

Dependent variable: Annual labour productivity growth

VARIABLES	Broadband (>30Mbit/s)	ERP	CRM	Computer use share	ICT training
Frontier growth	0.209***	0.207***	0.209***	0.226***	0.208***
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Time lagged gap to the frontier	0.124***	0.124***	0.124***	0.134***	0.124***
	(0.011)	(0.011)	(0.011)	(0.012)	(0.011)
Investment	0.037***	0.037***	0.037***	0.035***	0.037***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Firm age	0.001**	0.002**	0.001**	0.001**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exporter dummy	0.068***	0.068***	0.067***	0.061***	0.067***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Firm size 50-249 employees	-0.003	-0.004	-0.002	0.004	-0.008
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Firm size 250 and more employees	0.001	-0.002	0.002	0.016	-0.013
	(0.013)	(0.013)	(0.012)	(0.012)	(0.013)
Manufacturing, digital variable	0.011	0.045**	0.040**	0.120***	0.043***
	(0.014)	(0.017)	(0.019)	(0.035)	(0.015)
Services, digital variable	0.038***	0.041***	0.046***	0.139***	0.063***
	(0.009)	(0.009)	(0.009)	(0.017)	(0.014)
Constant	-0.291***	-0.303***	-0.295***	-0.338***	-0.288***
	(0.035)	(0.035)	(0.035)	(0.038)	(0.033)
Observations	10,368	10,368	10,368	10,191	10,368
R-squared	0.085	0.086	0.086	0.095	0.086

Note: This table reports results of an OLS regression as specified in equation (2) of this paper. Firm-level change of the natural logarithm of labour productivity is regressed on average change of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell, the firm's lagged gap to the productivity frontier, the change of the natural logarithm of the firm's non-current assets, firm age, a firm-level exporter dummy, firm size, the average age of employees in the firm, firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and the provision of ICT training to its employees, as well as the share of employees using computers for work purposes. Digital variables are interacted with a manufacturing dummy (NACE Rev. 2, 10-33) and a Services dummy (NACE Rev. 2, 45-82), respectively. All regressions include sector- and year fixed effects, and standard errors are clustered at the firm level. Firms at the sector-level productivity frontier are excluded from the regressions. Regressions are based on firm-level data from Estonia in 22 sectors (NACE Rev. 2, 10-82) over the period 2011-2016 for firms with 10 or more employees. To maximise coverage, averages of each digital variable are used over the period 2011-2016. Standard errors are in parentheses, ***, ** and * represent p<0.01, p<0.05 and p<0.1, respectively. Main results are highlighted.

Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education databases (all provided by Statistics Estonia).

21. The result could also be consistent with Gal et al. (2019) if sector spill-overs from digital adoption are higher in manufacturing than in services. This would solve the apparent mystery of manufacturing companies leaving money on the table, since only parts of the productivity gains from digitalisation at the sector level would be internalised by the firm doing the investment. To test this hypothesis, the same sector split is applied, but in the framework of Equation (4), accounting for sector spill-overs. Indeed, the results indicate considerable sector spill-overs within the manufacturing sectors for high-speed broadband, ERP, CRM, the share of workers using computers for work purposes and ICT training. The within effects for manufacturing are very similar to the specification that included sector fixed effects; nevertheless, it cannot be excluded that some of the between effects for manufacturing are due to factors that are correlated with both digital adoption and productivity growth. The coefficients for services sectors are considerably lower for all variables, and only significant (at the 95% level) for the share of employees using computers for work purposes and the ICT training variable (Table 6).

Table 6. Regression results, manufacturing vs services, including sector spill-overs

Dependent variable: Annual labour productivity growth

VARIABLES	Broadband (>30Mbit/s)	ERP	CRM	Computer use share	ICT training
Frontier growth	0.175***	0.173***	0.174***	0.187***	0.174***
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Time lagged gap to the frontier	0.090***	0.089***	0.090***	0.094***	0.089***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)
Investment	0.033***	0.033***	0.033***	0.031***	0.033***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)
Firm age (within)	0.002**	0.002***	0.002**	0.001**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Firm age (between)	-0.010***	-0.011***	-0.011***	-0.011***	-0.010***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Exporter (within)	0.050***	0.049***	0.049***	0.042***	0.048***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Exporter (between)	-0.095***	-0.080***	-0.086***	-0.106***	-0.091***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.023)
Firm size 50-249 employees	-0.002	-0.003	-0.001	0.003	-0.006
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Firm size 250 and more employees	-0.002	-0.009	-0.004	0.004	-0.017
	(0.013)	(0.013)	(0.013)	(0.012)	(0.013)
Manufacturing, digital variable (within)	0.008	0.038**	0.038*	0.110***	0.035**
	(0.013)	(0.018)	(0.020)	(0.037)	(0.015)
Manufacturing, digital variable (between)	0.176***	0.221***	0.337***	0.313***	0.473***
	(0.034)	(0.044)	(0.061)	(0.047)	(0.071)
Services, digital variable (within)	0.026***	0.031***	0.035***	0.109***	0.055***
	(0.009)	(0.009)	(0.009)	(0.015)	(0.013)
Services, digital variable (between)	0.012	0.004	0.008	0.043**	0.082**
	(0.022)	(0.035)	(0.031)	(0.017)	(0.036)
Constant	-0.017	-0.009	-0.006	-0.029	-0.025
	(0.033)	(0.031)	(0.031)	(0.031)	(0.031)
Observations	10,368	10,368	10,368	10,191	10,368
R-squared	0.064	0.064	0.065	0.071	0.065

Note: This table reports results of an OLS regression as specified in equation (2) of this paper. Firm-level change of the natural logarithm of labour productivity is regressed on average change of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell, the firm's lagged gap to the productivity frontier, the change of the natural logarithm of the firm's non-current assets, firm age, a firm-level exporter dummy, firm size, the average age of employees in the firm, firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and the provision of ICT training to its employees, as well as the share of employees using computers for work purposes. Sector average variables are denoted "between", while firm-level differences to their respective sector averages are denoted "within". Digital variables are interacted with a manufacturing dummy (NACE Rev. 2, 10-33) and a Services dummy (NACE Rev. 2, 45-82), respectively. All regressions include year fixed effects, and standard errors are clustered at the firm level. Firms at the sector-level productivity frontier are excluded from the regressions. Regressions are based on firm-level data from Estonia in 22 sectors (NACE Rev 2, 10-82) over the period 2011-2016 for firms with 10 or more employees. To maximise coverage, averages of each digital variable are used over the period 2011-2016. Standard errors are in parentheses, ***, ** and * represent p<0.01, p<0.05 and p<0.1, respectively. Main results are highlighted.
Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education databases (all provided by Statistics Estonia).

Routine intensity

22. If many of the tasks performed by workers within a firm are routine, they are presumably easier to streamline and automate with the help of digital technologies. Gal et al. (2019) find that digital adoption and productivity are more closely associated in sectors highly intensive in routine tasks than elsewhere. The indicator of routine intensity is defined on the sector level. Sector fixed effects thus capture the

information contained within this variable, meaning that this variable cannot be into the main specification in Equation (2). Augmenting equation (4) with the interaction between the sector-level digital variable and the routine content indicator is on the other hand possible (Table 7).

Table 7. Regression results, accounting for routine task intensity

Dependent variable: Annual labour productivity growth

VARIABLES	Broadband (>30Mbit/s)	ERP	CRM	Computer use share	ICT training
Frontier growth	0.164***	0.165***	0.164***	0.177***	0.166***
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Lagged gap to the frontier	0.083***	0.083***	0.082***	0.087***	0.082***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Investment	0.033***	0.033***	0.032***	0.030***	0.032***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)
Firm age (within)	0.002**	0.002***	0.002**	0.002**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Firm age (between)	-0.008***	-0.009***	-0.009***	-0.011***	-0.011***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Exporter (within)	0.045***	0.045***	0.044***	0.037***	0.045***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Exporter (between)	0.002	0.003	0.028*	0.040**	0.014
	(0.016)	(0.019)	(0.016)	(0.017)	(0.017)
Firm size 50-249 employees	0.002	0.001	0.005	0.008	-0.001
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Firm size 250 and more employees	0.000	-0.003	0.006	0.011	-0.012
	(0.013)	(0.013)	(0.013)	(0.012)	(0.013)
Digital variable (within)	0.016**	0.029***	0.033***	0.114***	0.037***
	(0.008)	(0.009)	(0.009)	(0.016)	(0.009)
Digital variable (between)	0.060*	-0.028	-0.077*	-0.061**	-0.084*
	(0.031)	(0.053)	(0.045)	(0.025)	(0.050)
Digital variable (between) X routine intensity	0.112***	0.102***	0.054	0.098***	0.198***
	(0.029)	(0.032)	(0.045)	(0.032)	(0.055)
Constant	-0.166***	-0.072**	-0.058*	-0.079**	-0.057*
	(0.043)	(0.031)	(0.032)	(0.033)	(0.031)
Observations	10,368	10,368	10,368	10,191	10,368
R-squared	0.060	0.060	0.059	0.066	0.059

Note: This table reports results of an OLS regression as specified in equation (2) of this paper, augmented with an interaction between the respective digital variables and the sector-level intensity of routine tasks (See Marcolin et al., 2016 for a description of the indicator). Firm-level change of the natural logarithm of labour productivity is regressed on average growth of the natural logarithm of labour productivity of the top 5 percent firms in each sector-year cell, the firm's lagged gap to the productivity frontier, the change of the natural logarithm of the firm's non-current assets, firm age, a firm-level exporter dummy, firm size, the average age of employees in the firm, firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and the provision of ICT training to its employees, as well as the share of employees using computers for work purposes. Sector average variables are denoted "between", while firm-level differences to their respective sector averages are denoted "within". All regressions include year fixed effects, and standard errors are clustered at the firm level. Firms at the sector-level productivity frontier are excluded from the regressions. Regressions are based on firm-level data from Estonia in 22 sectors (NACE Rev 2, 10-82) over the period 2011-2016 for firms with 10 or more employees. To maximise coverage, averages of each digital variable are used over the period 2011-2016. Standard errors are in parentheses, ***, ** and * represent p<0.01, p<0.05 and p<0.1, respectively. Main results are highlighted.

Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education (all provided by Statistics Estonia) and the OECD Survey of Adult Skills (2012) databases.

23. The results, consistent with Gal et al. (2019) and Chevalier and Luciani (2018), show that digitalisation is more closely related to productivity gains in sectors with high routine intensity, perhaps reflecting a higher potential to substitute technology for labour in these sectors. The coefficient is positive

and significant at the 99% level for all the digital variables, except high-speed broadband, which is significant at the 95% level.

Illustrations of economic significance

24. For ease of interpretation, and to illustrate the economic significance of the results, the regression coefficients are presented in a back-of-the-envelope re-scaling to make them comparable in Table 8. The table presents magnitudes from the sector perspective, by assuming 10 percentage points increase in the dependent variable. Coefficient estimates to calculate direct effects are from the main specification with sector fixed effects in Table 3. The adopting firm faces a binary choice to adopt a certain technology or not, and to provide ICT training or not, and the magnitudes thus represent 10 percentage points increase of adopting firms within a sector. The share of employees using computers at work is on the other hand a continuous variable, and the re-scaling implies a 10 percentage points increase in average computer use across companies within each sector. Sector spill-overs are calculated for a 10 percentage points increase of the dependent variable, using the positive and significant sector-level coefficients for manufacturing reported in Table 6. No sector effects are calculated for services.

Table 8. Productivity growth associated with digital adoption - Illustration of magnitudes

Annual labour productivity growth (in %) associated with a 10 percentage points higher value of the digital variables

	High-speed broadband	ERP software	CRM software	Computer use at work	ICT training
Direct effect	0.29	0.38	0.45	1.44	0.50
Sector spill-overs	0.83	1.04	1.58	1.47	2.22
Sector total	1.12	1.42	2.03	2.91	2.72

Note: This table presents re-scaled regression coefficients presented in Table 3 (Direct effects) and Table 6 (Sector spill-overs) to illustrate economic magnitudes of the results for Estonian firms with 10 or more employees. See the respective table notes for a detailed specification. The sector average direct and spill-over effects are calculated for a 10 percentage point increase in the dependent variable. Spill-over effects are scaled by manufacturing's share of total net profits in the sample (approximately 47%) to arrive at an estimate of the average effect for the total sample. Columns show (re-scaled) results for firm-level dummy variables of the adoption of broadband (>30Mbit/s), ERP software, CRM software and a firm's provision of ICT training to its employees, as well as the share of employees using computers for work purposes.

Source: Author's calculations based on linked data from the Community Survey on ICT Usage and e-commerce in Enterprises, Annual bookkeeping reports, Statistical register of economic units, Trade in Goods and Services, Register of employment and the Statistical register of education databases (all provided by Statistics Estonia).

25. Productivity growth premiums are substantial from the adopting firm's perspective, standing between 3% and 4% for adopting individual digital technologies, approximately 5% for providing ICT training, and 0.14% from each percentage point increase in the share of employees using computers for work purposes. This translates into increased sector-level growth rates ranging from 0.3% to 0.5% for increasing the binary variables by 10 percentage points, and 1.4% for increasing the share of employees using computers for work purposes. Sector spill-overs are also substantial, ranging from 0.8% to 2.2%. Spill-overs from ICT training are notably high compared to the direct effect, at 2.2%. Combining direct and spill-over effects, sector level productivity premiums range from 1.1% for high-speed broadband, to 2.9% for the share of employees using computers for work purposes.

Summary and conclusions

26. With a newly constructed firm-level dataset, this paper explores productivity growth premiums of the adoption of concrete digital technologies and digital skill use variables. A novelty is that the results

disentangle the direct effects on the firms actually adopting the technologies from indirect effects from the sector-level digital intensity. The results show a clear productivity growth premium for digitally intensive firms. The evidence also suggests positive effects for the average firm belonging to a digitally intensive sector. These positive spill-overs are not universal, but relate to manufacturing sectors and sectors with a high routine task content and thus a high automation potential. Lower spill-overs and higher firm-specific productivity gains in services could reflect stronger complementarities between digitalisation and hard to copy firm-specific assets. If this is the case, it would give the firm strong incentives to invest, but at the same time increase market power.

27. The economic argument for causality is clear, since increasing productivity would typically be the main motive for private firms to digitalise. The finding in this paper that higher rates of digital adoption in services sectors mirror the firm-level estimates of productivity associated with digital adoption supports this argument. However, endogeneity issues cannot be ruled out, notably in the firm-level estimates, as more capable firms may also be more inclined to digitalise. Setting these concerns aside and assuming causality, a first lesson from these results is that firms have an incentive to become more digital intensive. Productivity growth premia directly attributable to the adopting firms are substantial, ranging from approximately 3% to 5% for the different digital variables. A second lesson is that firms in manufacturing industries see returns from digitalising that are lower than in services sectors, and substantially lower than social returns, as sectoral spill-overs are substantial. Spill-over effects are notably large in providing ICT training. Lower private returns to digital adoption and skill use in manufacturing sectors relative to services may contribute to explain why manufacturing firms appear to be less digitally intensive than firms in services sectors on average.

28. Without policy intervention there is a risk of under-investment in digital technologies and skill use. For example, increasing the share of employees using computers for work purposes in a sector by 10 percentage points is associated with a 1.4% direct productivity growth premium in a firm increasing digital skill use share in line with the sector average firm. Positive spill-overs from other adopting firms in the sector are associated with a further 1.5%[4] higher productivity in the same firm, independently of the firm's own digitalisation efforts. In other words, only about half of the social returns of digital adoption would directly benefit the adopting firm in this particular case. The discrepancy between private and social returns is even higher in the provision of ICT training to employees, where private returns only constitute a fifth of social returns.

29. Future research could add considerable value by extending the time coverage of digital variables. This could potentially allow researchers to investigate the causal link between digital adoption and productivity further. Furthermore, the technologies included in this paper only represent a sub-set of potentially productivity enhancing technologies, not fully representing today's technological frontier, and fully ignoring new technologies of tomorrow. Expanding the analysis with for example cloud computing and artificial intelligence would be informative in this respect. Likewise, extending country coverage could give useful insights into the general applicability of the findings.

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[4] This is the economy-wide average reported in Table 8. The estimated effect in manufacturing sectors is approximately the double, while it is considerably smaller in services.

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