IARIW 2024

IARIW 2024

Thursday, August 22 – Friday, August 30

Cloud Computing, ICT Investments and Productivity

Thomas Niebel

(ZEW Mannheim)

Niklas Schomburg

(University of Bremen)

Paper prepared for the 38th IARIW General Conference
August 26-30, 2024

Session 7D-1, Productivity/investment

Time: Friday, August 30, 2024 [14:00-15:30 GMT]

Cloud computing, ICT investments and productivity

Thomas Niebel *[1] and Niklas Schomburg †[2]

[1] *ZEW Mannheim*
[2] *University of Bremen*

July 31, 2024

Abstract

Our paper complements the existing research by analyzing the relationship of cloud adoption and ICT investments as well as cloud adoption and productivity at the industry-level. Our analysis is based on combination a of the EUKLEMS – INTANProd database and the Eurostat ICT Survey on ICT Usage and E-Commerce in Enterprises of the years 2014 to 2020 for 19 industries and 17 European countries. We find no evidence that cloud adoption is a substitution for own ICT investments in general. However, we find a substitution pattern for investments in IT Hardware, especially in the service sector. Furthermore, we find a positive relationship between cloud adoption and industry level labor productivity, but only in the manufacturing sector.

Keywords: Cloud computing, ICT investments, productivity

---

[*] Corresponding author: ZEW – Leibniz Centre for European Economic Research, *email*: `thomas.niebel@zew.de`, P.O. Box 103443, 68034 Mannheim, Germany. We like to thank the participants at the TPI Brown Bag Seminar and the EUKLEMS-INTANProd workshop in Rome for helpful comments and suggestions. This paper has been written as part of the project "Development and Measurement of the Digitalisation of the Economy in Germany" funded by the German Federal Ministry of Economic Affairs and Climate Action. For further information on the author's other projects see `www.zew.de/staff_tni`.

[†] University of Bremen, *email*: `nschombu@uni-bremen.de`, P.O. Box 33 04 40, 28359 Bremen, Germany.

1 Introduction

Cloud computing has become a driving force in the ongoing digital transformation by fundamentally changing the dynamics through which firms acquire information and communication technologies (ICT). Formerly, firms often had to make substantial upfront investments in ICT infrastructure to be able to reap the benefits of adopting digital technologies. In addition, the initial investment barrier increased the risk of digital adoption as the invested capital was often sunken in the case that a digitalization project would not produce the desired effects.

Cloud solutions reduce the capital-intensity of digital technology adoption by allowing firms to source the necessary ICT capabilities like storage, processing and software as an 'on demand' service from cloud providers. Instead of needing to invest into the buildup of considerable on premise ICT infrastructure, firms 'pay as you go' for the ICT capabilities they actually use. Purchased as a service, ICT shifts from a fixed to a predominantly variable cost. This allows firms to quickly scale their ICT capabilities according to their immediate production needs. This 'scale without mass' has been claimed to enable new business models, facilitates innovation and creates novel firm types (DeStefano et al., 2023).

The diffusion of cloud computing in Europe has been at a staggering rate over the last years. Whereas only 18 percent of European companies used cloud computing services in 2014 the share since increased to 41 percent in 2021 (Haucap et al., 2022). Furthermore, rising competition and economies of scale led to a steep decline in prices. For example, Byrne et al. (2018) estimate that the real prices for Amazon Web Service's (AWS) database product fell at an average rate of 11 percent per year while their storage product even fell at 17 percent per year during 2009-2016. The trend towards cloud computing is expected to continue with the European cloud computing market being estimated to grow from 65.6 billion euro in 2021 to 157.6 billion euro by 2027 (Statista, 2022).

Against this background, it becomes important to understand the economic consequences of cloud computing. This paper makes inferences into two hypothesized effects. First, reducing the need for upfront ICT investments has been proclaimed to be one of the major advantages of cloud solutions (OECD, 2014; Gal et al., 2019; DeStefano et al., 2023). Hence, it could be hypothesized that cloud solutions might be partly a substitute for ICT capital and thus might reduce overall ICT investments. From an empirical viewpoint current research results are scarce and mixed. DeStefano et al. (2023) find that cloud adoption leads to a reduction in IT and software investments in a sample of UK firms. On the contrary, Duso and Schiersch (2022) find no effect of cloud adoption on ICT investment for German firms.

Second, cloud adoption might influence productivity through multiple channels. In addition to the cost reduction from eliminating the need for upfront investments, cloud customers might further benefit from the economies of scale enjoyed by cloud providers (Benlian and Hess, 2011; Jin and McElheran, 2017). Moreover, cloud services might improve the adoption of other to digital technologies. These digital technologies in turn increase productivity (Cardona et al., 2013; Brynjolfsson and McAfee, 2014; Bertschek et al., 2015; Bertschek and Niebel, 2016). In this regard, young and small firms whose capital constraints often make on premise adoption of high-tech digital solutions prohibitively expensive might especially benefit from the flexible access provided by cloud services (Jin and McElheran, 2017; Bloom and Pierri, 2018).

We complement the existing research by analyzing the relationship of cloud adoption and ICT investments as well as cloud adoption and productivity at the industry-level. Our analysis is based on combination of the EUKLEMS – INTANProd database (Bontadini et al., 2023) and the Eurostat ICT Survey on ICT Usage and E-Commerce in Enterprises of the years 2014 to 2020 for 19 industries and 17 European countries. We do not find empirical evidence that cloud adoption is a substitution for own ICT investments in general. However, we find a substitution pattern for investments in IT Hardware, especially in the service sector. Furthermore, we find a positive relationship between cloud adoption and industry level labor productivity, but in line with Gal et al. (2019) and Duso and Schiersch (2022), only in the manufacturing sector.

The paper is organized as follows. Section 2 provides an overview of the existing literature. Whereas Sections 3 and 4 describe the data and the empirical framework. Section 5 presents the econometric results and discusses their implications. Section 6 concludes.

2 Related Literature

ICT investments have been in decline in most OECD countries over the last decade. While in 2001 ICT investments accounted for 3.5 percent of GDP in the OECD, this ratio has dropped to 2.7 percent in 2014 (Cette et al., 2019). Although it is suggested that ICT investments are underestimated in official statistics (Byrne and Corrado, 2017), the downwards trend is still observable if indirect ICT investments embodied in final products are accounted for (Cette et al., 2019). One factor contributing to the decline of aggregated ICT investments might be the switch to cloud computing. A major advantage of cloud computing is argued to be the elimination of upfront investments to a great extent when adopting digital technologies (OECD, 2014; Gal et al., 2019; Byrne et al., 2021; Duso and Schiersch, 2022; DeStefano et al., 2023).

Accessing ICT capabilities through purchased cloud services transforms ICT from a fixed investment to an intermediate input.[1] From a global perspective, even though cloud providers also have to invest in ICT, global ICT investments might be lower as the utilization of these investments are usually higher in the cloud (Byrne et al., 2021). At the firm level, it could also be hypothesized that cloud adoption by firms reduces their ICT investment. However, there is suggestive evidence that firms might incorporate cloud computing in their digitalization strategy differently. In their recent cloud monitor KPMG (2022) asks 478 German firms to describe their cloud strategy. Only 9 percent of companies stated that they follow a 'Cloud-Only-Strategy' which aims at migrating all IT systems to the cloud. 40 percent of surveyed companies answered that they employ a 'Cloud-First-Strategy' which prescribes that new IT projects should be preferably but not necessarily implemented via the cloud. 21 percent of companies use cloud services primarily as a complement to existing ICT infrastructure as part of a 'Cloud-Too-Strategy', while 27 percent have no specific cloud strategy.[2] The variety of strategies hint at the heterogeneous effects cloud adoption might have on ICT investment. Whereas a 'Cloud-Only-Strategy' would suggest that the respective firms view cloud services as a substitute for ICT investment, the 'Cloud-Too-Strategy' insinuates a more complementary status. In line with the complementarity argumentation, circumventing the traditional upfront investment barrier via cloud services seems to allow firms to adopt more complex

---

[1] Identifying and measuring cloud services within the National Accounts remains challenging with respect to various aspects like deflators and international sourcing of cloud services (Coyle and Nguyen, 2018; Baer et al., 2020; Byrne et al., 2021; Ker, 2021; Reinsdorf, 2021; Coyle and Hampton, 2024)

[2] 4 percent gave no response.

digital technologies (Zolas et al., 2020). As a consequence, the reduced ICT investment due to cloud adoption might be compensated by increased investment in more complex digital technologies.

Thus the direction of the net effect of cloud computing remains ambiguous. Empirical evidence remains scarce and inconclusive. DeStefano et al. (2023) find that cloud adoption is negatively associated with IT investment per employee at the firm-level for a sample of UK firms. This effect seems to be stronger in incumbent firms compared to young ones. Duso and Schiersch (2022), however, find no effect of cloud computing on IT Investment for a sample of German firms. The results remain robust when the authors control for potential endogeneity arising from self-selection into cloud adoption.

Purchasing ICT services via cloud providers instead of investing in ICT assets has the potential to affect productivity through multiple channels. Cloud providers might reduce the price to access certain ICT capabilities. The scale of cloud providers' ICT asset purchases is likely to give them significant bargaining power resulting in sizeable quantity discounts. Moreover, cloud providers have a higher utilization of their ICT assets. This implies that they need less ICT assets to produce a given level of ICT services compared to individuals firms (Byrne and Corrado, 2017). In addition, cloud providers have been found to conduct sizeable own-account ICT asset production (Byrne et al., 2018). On the one hand, own-account production eliminates the added profit margin embodied in the price of purchased assets. On the other hand, cloud providers can tailor their own-account ICT assets towards their specific needs which might increase asset-quality and cost-effectiveness. Lastly, cloud providers also enjoy economies of scale in the maintenance of their ICT infrastructure (Jin and McElheran, 2017; Benlian and Hess, 2011). Taken together, cloud providers enjoy a significant cost-advantage which they pass on, to a certain extent, to their customers. Empirical evidence provided by Byrne et al. (2018) shows that the quality-adjusted prices for cloud services provided by the market leader Amazon Web Services have been in decline since the launch of their first product lineup in 2006. The downwards trend has accelerated since 2014 after the market entrance of several large competitors like Microsoft Azure and Google Cloud.

Purchasing cloud services might increase the propensity to adopt other, sometimes more advanced, digital technologies which might positively affect productivity. Coyle and Nguyen (2019) argue that cloud services lower the entry barrier to more complex production techniques by largely eliminating the need for considerable upfront investments to access the required ICT capabilities. Zolas et al. (2020) show that firms follow a hierarchy of increasing technological sophistication generally moving from adopting basic to more advanced digital technologies. Within this taxonomy cloud computing is categorized as an intermediate technology. However, firms that use cloud services show an increased likelihood to adopt more advanced digital technologies and thus move up the hierarchy more quickly. This enabling function might be especially salient in the context of facilitating the spread of data-driven business models (Coyle and Nguyen, 2019). As those business models require firms to store and process vast amounts of data, cloud solutions offer low cost access to the required ICT capabilities. Novel evidence present by Cho et al. (2023) support this claim. They find that cloud computing significantly increases the propensity of firms to adopt advanced digital technologies that require the storage and processing of fast amount of information like Big Data, AI, IoT or 5G. Furthermore, data as an input (intangible asset) in the production process is argued to have the potential to significantly increase labor productivity (Corrado et al., 2022).

Empirical evidence for the productivity enhancing effect of cloud computing is mixed and seem to indicate that a positive effect is conditional on specific firm- and industry characteristics. At the macro level, Byrne and Corrado (2017) analyze the effect of ICT on labor productivity growth in the U.S. using a multi-sector growth-model. Although the total contribution of IT is quite sizeable with 1.4 percent per year, the effect of cloud computing seem to be hardly detectable. Two firm characteristics that seems to modulate the effect of cloud computing are firm size and firm age. Borowiecki et al. (2021) analyze the effect of several digital technologies, including cloud computing, on firm-level labor productivity in a sample of Dutch firms. They find no impact of cloud computing for the complete sample, however a borderline positive effect for small firms is detected. Using micro-level data on UK firms, Romanko (2021) find that cloud adoption bears initial installation costs which result in a short-term negative productivity effect. However, over time firms learn to use cloud computing effectively. With every year after the adoption cloud computing increases productivity by 1 percent. The break-even point is reached after 2-3 years. The productivity-enhancing effect is stronger for smaller firms which also compensate faster for the initial expenses. Jin and McElheran (2017) analyze the effect of switching from traditional ICT capital investment to cloud computing, approximated by IT services, on the survival and productivity of U.S. manufacturing firms. While they find that cloud adoption generally increases the survival probability, a productivity-enhancing effect was only statistically significant for a sub-sample of young firms. DeStefano et al. (2023) study the impact of cloud computing on firm growth, labor productivity for firms in the UK. The authors use time variation in the availability of fiber broadband as well as the variation in the distance to the exchange as instruments to account for potential endogeneity of cloud adoption. They find a positive impact of cloud computing on labor productivity and employment for young firms but only weak productivity effects of cloud computing for incumbent firms.

Empirical evidence suggests that the productivity-enhancing effect is heterogeneous across industries. To circumvent data limitation issues on firm-level cloud adoption, Candel Haug et al. (2016) construct an indicator of ’cloud adaptiveness’ by analyzing the usage and combination of ICT infrastructure of European firms. Firms with a certain ICT structure “are likely to introduce cloud computing at some point, in other words, they are cloud ready or cloud adaptive”. The authors find that although firms in the service sector are more cloud adaptive on average, cloud adaptiveness has no effect on labor productivity. However, cloud adaptive firms in the manufacturing sector are found to have significantly higher labor productivity than non-cloud adaptive firms. These observations hold when MFP is used as an alternative measure for productivity. Gal et al. (2019) analyze the effect of cloud computing on MFP growth within a sample of OECD Firms. They merge firm-level data from the ORBIS database with industry-level data on digital adoption from the Eurostat “Community Survey on ICT Usage and E-Commerce in Enterprise” and data on industry characteristics from OECD and Eurostat. They find that cloud computing has a positive effect on MFP growth in the manufacturing sector but has no effect in the service sector. In a next step, the authors inquire into which industry characteristics might modulate the effect of cloud computing. Their results show that industries with a high routine task intensity seem to benefit most from cloud adoption. Furthermore, skill shortages within an industry significantly reduces the productivity-enhancing effect of complex cloud computing solutions. Duso and Schiersch (2022) use a sample of German firms to estimate the impact of cloud computing on labor productivity. Their baseline OLS results indicate that cloud computing has a positive effect on labor productivity only for firms in manufacturing. Employing an endogenous treatment model using municipal-level broadband availability as an exogenous shifter to control for self-selection into cloud adoption they also find a positive and even stronger effect for firms in the information and communication services sector. However, cloud computing has no significant effect for firms in business services and other services in both the OLS and endogenous treatment model. However, a recent study by Katz and Jung (2024), finds for a sample of OECD countries that an increase in cloud penetration is positively correlated with an increase in labor productivity.

3 Data and Descriptive Statistics

Our analysis makes use of two main data sources at the industry level. The EUKLEMS – INTANProd database (Bontadini et al., 2023) provides detailed information on output, labor input as well as capital input.[3] Especially relevant for our analysis is the detailed information on ICT and non-ICT investments as well as capital stocks. For ICT, disaggregated data for computing equipment (IT), communications equipment (CT) as well as computer software and databases (Soft_DB) is provided up to the year 2020. The second main data source are the industry level numbers of the Eurostat ICT Survey on ICT Usage and E-Commerce in Enterprises (Eurostat ICT)[4]. The questionnaires of the Eurostat ICT survey are harmonized across all countries within the European Union. Information for cloud computing adoption was first available in the year 2014. The merged (unbalanced) sample of both data sets provides information for the year 2014 to 2020 for 19 industries and 17 European countries. Apart from the general adoption, there is also information on the type of cloud usage and the purpose (basic cloud vs more advanced cloud technologies). There are however some limitations to the Eurostat ICT data. The information on cloud computing cloud is just a binary measure and has no direct data on the intensity use (just the share of cloud adopters by industry). Furthermore, the questions on cloud usage are usually mandatory only every second year.[5] After the merge with the EUKLEMS – INTANProd database and controlling for missings in all variables, we are left with 1224 observation in our estimation sample.[6] Table 3.1 presents the average adoption rate of cloud computing in the estimation sample with and without interpolation.[7] On average, about 32 percent of the firms within the industries of our sample have public adopted cloud solutions. For more advanced cloud services (high CC services)[8], it is about 20 percent.

Table 3.1: Cloud Computing Adoption - Estimation Sample

	N	Mean	Median	SD	Min	Max
Buy cloud computing services (*Cloud*)	1224	.32	.27	.2	.021	.95
Buy high CC services (*Cloud_HIGH*)	1113	.2	.15	.16	.0088	.83
Buy cloud computing services (no interpolation - *Cloud_orig*)	845	.31	.25	.19	.021	.95
Buy high CC services (no interpolation - *Cloud_HIGH_orig*)	798	.19	.14	.15	.0088	.83

NOTES: Variables with (no interpolation) are based on the raw values from Eurostat ICT survey. All other variables are enriched with linear interpolations.

---

[3] For a general overview of the EU KLEMS database see O'Mahony and Timmer (2009), Inklaar et al. (2020), Fernald et al. (2023), Gouma and Inklaar (2023) and Van Ark et al. (2024).

[4] See e.g. Nicoletti et al. (2020).

[5] 2014, 2016, 2018 and 2020. See Figure A.2 in the Appendix.

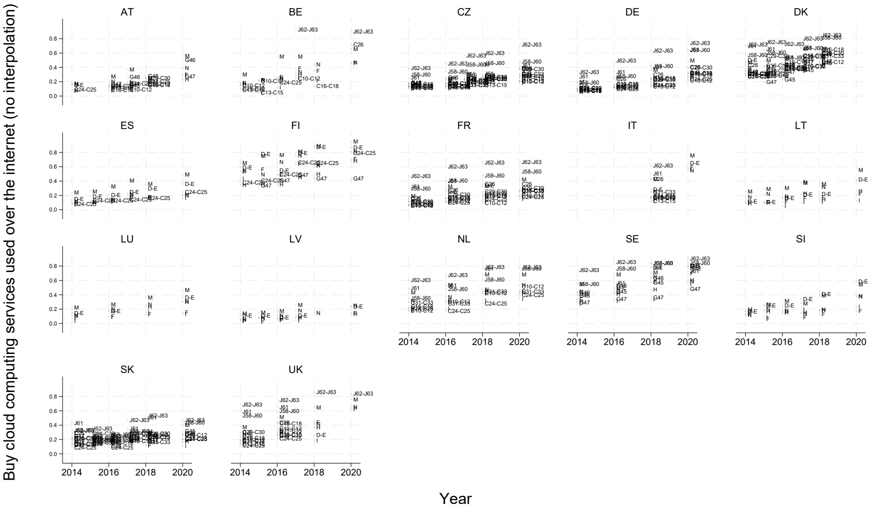
[6] See Table A.3 in the Appendix. Theoretically, there are 2261 observations (7 year, 17 countries and 19 industries).

[7] A detailed description of all variables is provided in Table A.2 in the Appendix. Descriptive statistics for all variables are shown in Table A.4 also in the Appendix.

[8] High CC services: accounting software applications, CRM software and computing power)

Figure 3.1[9] present the share of firms that adopted cloud services by country and industry over time. It shows a clear upward trend over time in all countries but also substantial differences between industries and countries. As expected, we usually see high adoption rates in industry $J62\_J63$ (computer programming, consultancy, and information service activities) as well as M (professional, scientific and technical activities).[10] Figure A.4[11] in the Appendix compares the share of ICT investment in value added with the share of firms adopting cloud services at the industry level. Only for a subset of countries, there seems to be a correlation between ICT investments and cloud computing adoption. Based on this graphical representation there is no clear indication for our first research question on whether cloud computing and ICT investments are rather substitutes or complements.

Figure 3.1: Share of Cloud Usage by Country/Year/Industry - Estimation Sample



Source: Eurostat Community survey on ICT usage and e-commerce in enterprises.

4 Empirical Framework

The goal of the paper is to find (descriptive) evidence whether public cloud computing and ICT investment are complements or substitutes and whether cloud adoption is related to higher labor productivity at the industry level. For the relationship between cloud adoption and ICT investment we follow Duso and Schiersch (2022) and estimate the following equation:

$$\ln Iq\_ICT_{c,j,t} = \beta_{ICT} \ln Kq\_ICT_{c,j,t-1} + \beta_{NICT} \ln Kq\_NICT_{c,j,t-1} + \beta_{CC} CC_{c,j,t} + \epsilon_{c,j,t} \qquad (1)$$

The dependent variable $Iq\_ICT_{c,j,t}$ are the real investments in ICT capital in country c in industry j at time t. We control for the lagged ICT (Kq_ICT) and Non-ICT (Kq_NICT) capital stock. A positive β_{CC} would mean that cloud adoption and ICT investment are complements, a negative value of β_{CC} that cloud adoption and ICT investment are substitutes.

---

[9] See Figure A.1 in the Appendix for the same Figure but with interpolated values for cloud computing adoption.

[10] For some countries like Luxembourg, data are only available for the more aggregated industries, due to confidentiality and/or data quality reasons.

[11] See Figure A.5 in the Appendix for the same Figure but with interpolated values for cloud computing adoption.

Again loosely following Duso and Schiersch (2022), possible productivity gains from cloud computing are modelled as an augmented Cobb-Douglas production function:

$$\ln va_{c,j,t} = \beta_L \ln L_{c,j,t} + \beta_K \ln Kq_{c,j,t} + \beta_{CC} CC_{c,j,t} + \epsilon_{c,j,t} \tag{2}$$

with $va_{c,j,t}$ being real value added per hour worked, $L_{c,j,t}$ hours worked and $Kq_{c,j,t}$ total real capital stock.[12] All regressions include country x industry specific Fixed Effects. Due to the limitations of the industry-level data (limited time span and partially rather aggregate industry aggregations), we are only able to present controlled correlations, and do not claim a causal interpretation of the results.

5 Econometric Results

5.1 Cloud Computing Adoption and ICT Investments

In this Section we analyze whether ICT investment are complements or substitutes.[13] Table 5.1 provides the results of Fixed Effects regression of Equation (1). The six columns vary with respect to the interpolated (*Cloud*) or the raw cloud adoption (*Cloud_orig*) and whether we focus on the full sample or the manufacturing or services subsamples. However, all specifications show the same results. We cannot find any significant relationship between cloud adoption and ICT investments at the industry level.

Table 5.1: Dependent Variable: Ln(Real ICT Investment)

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud	-0.1395		0.2225		-0.1449	
	(0.200)		(0.333)		(0.246)	
Cloud_orig		-0.1717		0.0920		-0.0988
		(0.220)		(0.412)		(0.256)
$ln(Kq\_ICT_{t-1})$	-0.2532**	-0.3012*	-0.5089**	-0.4975**	-0.0898	-0.1053
	(0.120)	(0.153)	(0.192)	(0.193)	(0.125)	(0.147)
$ln(Kq\_NICT_{t-1})$	0.4313	0.6890**	1.4364**	1.4871**	0.1860	0.4552*
	(0.310)	(0.292)	(0.605)	(0.667)	(0.338)	(0.251)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample		Manufacturing		Services	
Adjusted R^2	0.265	0.281	0.308	0.308	0.271	0.277
Observations	1224	845	318	215	670	463

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table 5.2 provides the results for disaggregated ICT investments. We now find a significant negative relationship between cloud adoption and IT Hardware (*IT* - columns 2), at least for the non-interpolated cloud adoption variable (*Cloud_orig*). So there seems to be a substitution pattern between cloud and

---

[12] As a robustness check, Section 5.3 presents regression results with labor and capital services instead of hours worked and capital stocks as factor inputs.

[13] Appendix A.1 provides a basic analysis on whether cloud adoption leads to decline in the number of in-house IT specialists.

IT Hardware. For the other two types of ICT investments (*CT*: communications equipment, *Soft_DB*: computer software and databases), there is no such relationship.

Table 5.2: Relationship Between Cloud Adoption and ICT investment - Dependent Variable: Ln(Real IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)
	IT		CT		Soft_DB	
Cloud	-0.4447		-0.1828		0.0103	
	(0.276)		(0.323)		(0.254)	
Cloud_orig		-0.6998**		-0.3259		0.1038
		(0.276)		(0.353)		(0.299)
$ln(Kq\_ICT_{t-1})$	-0.2029	-0.2444	0.0940	0.1841	-0.1299	-0.2123
	(0.166)	(0.191)	(0.137)	(0.164)	(0.144)	(0.181)
$ln(Kq\_NICT_{t-1})$	0.2633	0.3230	0.3443	0.1699	0.5053	0.7354**
	(0.325)	(0.366)	(0.350)	(0.435)	(0.335)	(0.320)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.059	0.101	0.084	0.058	0.253	0.255
Observations	1224	845	1224	845	1224	845

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. *IT*: computing equipment, *CT*: communications equipment, *Soft_DB*: computer software and databases. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

To further investigate this relationship. Table 5.3 presents the very same regressions as in Table 5.2 but for the manufacturing and services sector subsamples. It shows that the results in Table 5.2 are driven by the service sector. Only for the service sector we find a negative relationship (i.e. substitution) between cloud adoption and investments in IT Hardware (*IT*).[14]

---

[14] The same holds if we use the raw cloud data instead of the interpolated values as shown in Table A.5 in the Appendix.

Table 5.3: Relationship Between Cloud Adoption and ICT investment - Manufacturing vs. Services - Dependent Variable: Ln(Real IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)
	IT		CT		Soft_DB	
Cloud	0.2379	-0.5036*	0.6217	-0.2620	-0.0183	0.0239
	(0.781)	(0.290)	(0.580)	(0.462)	(0.380)	(0.359)
$ln(Kq\_ICT_{t-1})$	-0.6045**	0.0474	0.1232	0.1926	-0.3055	-0.0744
	(0.250)	(0.161)	(0.156)	(0.198)	(0.257)	(0.131)
$ln(Kq\_NICT_{t-1})$	0.8661	0.4249	-0.8570	0.5465	2.0333**	-0.0123
	(1.003)	(0.306)	(0.744)	(0.446)	(0.771)	(0.338)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Manufacturing	Services	Manufacturing	Services	Manufacturing	Services
Adjusted R^2	0.149	0.030	0.010	0.108	0.286	0.292
Observations	318	670	318	670	318	670

NOTES: *IT*: computing equipment, *CT*: communications equipment, *Soft_DB*: computer software and databases. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table 5.4 makes a distinction between sectors according their digital intensity based on the taxonomy from Calvino et al. (2018). The only significant relationship between cloud and ICT investments can be found for IT Hardware (IT) in sectors with a low digital intensity. This result is driven by service sector industries with low digital intensity (see Table A.7).

Table 5.4: Relationship Between Cloud Adoption and ICT investment - High vs Low Digital Intensive Sectors - Dependent Variable: Ln(Real ICT/IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ICT		IT		CT		Soft_DB	
Cloud	-0.0124	-0.2195	-0.8102*	0.0778	-0.6336	0.3910	0.3850	-0.3600
	(0.316)	(0.187)	(0.448)	(0.303)	(0.517)	(0.373)	(0.374)	(0.251)
$ln(Kq\_ICT_{t-1})$	-0.3110*	-0.1744	-0.3509	-0.1349	-0.0541	0.2367	-0.0110	-0.2303
	(0.171)	(0.138)	(0.264)	(0.179)	(0.194)	(0.194)	(0.206)	(0.170)
$ln(Kq\_NICT_{t-1})$	0.7170	0.3418	-0.5293	0.6354**	0.2562	0.4198	1.2248	0.2992
	(0.731)	(0.341)	(0.914)	(0.312)	(0.875)	(0.422)	(0.808)	(0.359)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Low	High	Low	High	Low	High	Low	High
Adjusted R^2	0.238	0.290	0.090	0.049	0.101	0.073	0.203	0.313
Observations	570	654	570	654	570	654	570	654

NOTES: *IT*: computing equipment, *CT*: communications equipment, *Soft_DB*: compute software and databases. Digital intensity (High vs Low) based on the taxonomy from Calvino et al. (2018). Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

5.2 Cloud Computing and Labor Productivity

In this Section we present fixed effects regressions of Equation (2) based on an augment Cobb-Douglas production function. We investigate the relationship between industry level cloud adoption (share of firms using public cloud computing services) and labor productivity. Table 5.5 therefore provides descriptive evidence whether there are additional gains from using public cloud services. Apart from a standard production function without cloud computing (Column 1), Columns (2) - (6) of Table 5.5 vary with respect to the inclusion of year dummies, different measures of cloud computing and whether the total capital stock or a split up into ICT and Non-ICT capital are included as regressors. For all but the specification without year dummies, we do not find any significant relationship between cloud computing adoption and industry labor productivity.[15]

Table 5.5: Dependent Variable: Ln(Real Value Added/Hours Worked) - Full Sample

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud		0.1273***	0.0436		0.0396	
		(0.040)	(0.064)		(0.063)	
Cloud_orig				0.0361		0.0327
				(0.069)		(0.069)
ln(*Hours*)	-0.0170	0.0510	-0.0222	0.0573	0.0021	0.0828
	(0.081)	(0.071)	(0.080)	(0.084)	(0.080)	(0.084)
ln(*Kq_GFCF*)	0.1306*	0.1703***	0.1354*	0.0968		
	(0.069)	(0.060)	(0.069)	(0.072)		
ln(*Kq_ICT*)					0.0358	-0.0030
					(0.027)	(0.033)
ln(*Kq_NICT*)					0.0580	0.0408
					(0.056)	(0.059)
Year DVs	Yes	No	Yes	Yes	Yes	Yes
Adjusted R^2	0.110	0.091	0.111	0.092	0.107	0.087
Observations	1224	1224	1224	845	1224	845

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

As in Section 5.1, we further investigate whether there are differences between the manufacturing and the services sector. These results are shown in Table 5.6. The coefficients for cloud computing in the manufacturing sector in Columns (3) and (4) are indeed now positive and statistically significant at the 10 percent level, no matter whether we employ the raw cloud computing data or the interpolated values. So at least for the manufacturing sector there is some indication or positive effects of cloud computing adoption on labor productivity. This result is in line with Gal et al. (2019) as well as Duso and Schiersch (2022).

---

[15] We neglect the significant coefficient without year dummies as it is very likely that our cloud variable is just capturing year specific shocks.

Table 5.6: Dependent Variable: Ln(Real Value Added/Hours Worked) - Manufacturing vs. Services

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud	0.0436		0.2644*		-0.0377	
	(0.064)		(0.143)		(0.081)	
Cloud_orig		0.0361		0.3206*		-0.0667
		(0.069)		(0.183)		(0.087)
$ln(Hours)$	-0.0222	0.0573	-0.0545	0.0704	0.0321	0.1077
	(0.080)	(0.084)	(0.235)	(0.249)	(0.090)	(0.092)
$ln(Kq\_GFCF)$	0.1354*	0.0968	0.3535	0.2347	0.1261	0.0985
	(0.069)	(0.072)	(0.232)	(0.247)	(0.086)	(0.091)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample		Manufacturing		Services	
Adjusted R^2	0.111	0.092	0.145	0.105	0.140	0.133
Observations	1224	845	318	215	670	463

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Tables 5.7, 5.8 and A.11 reveal a very interesting pattern. The results shown in those tables indicate that cloud computing adopters in less digitalized services industries even experience a decline in labor productivity.

Table 5.7: Dependent Variable: Ln(Real Value Added/Hours Worked)

	(1)	(2)	(3)	(4)	(5)	(6)
$ln(Hours)$	-0.0241	0.0554	-0.0100	0.0451	-0.0731	0.0231
	(0.079)	(0.083)	(0.093)	(0.099)	(0.229)	(0.243)
$ln(Kq\_GFCF)$	0.0891	0.0437	0.0695	0.0348	0.3778*	0.3000
	(0.071)	(0.074)	(0.089)	(0.094)	(0.226)	(0.247)
Cloud	-0.1231		-0.4808***		0.3269*	
	(0.082)		(0.132)		(0.195)	
D_OECD_By=1 × *Cloud*	0.2574***		0.5280***		-0.0892	
	(0.072)		(0.123)		(0.154)	
Cloud_orig		-0.1487		-0.5967***		0.4730*
		(0.093)		(0.145)		(0.255)
D_OECD_By=1 × *Cloud_orig*		0.2862***		0.6471***		-0.2100
		(0.083)		(0.140)		(0.199)
Sample	Full	Full	Services	Services	Manufacturing	Manufacturing
Adjusted R^2	0.133	0.117	0.198	0.216	0.144	0.112
Observations	1224	845	670	463	318	215

NOTES: *D_OECD_By* = 0 Industry with low digitalization level; *D_OECD_By* = 1 Industry with high digitalization level. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table 5.8: Dependent Variable: Ln(Real Value Added/Hours Worked)

	(1)	(2)	(3)	(4)	(5)	(6)
D_OECD_By=0	-0.1231	-0.1487	-0.4808***	-0.5967***	0.3269*	0.4730*
	(0.082)	(0.093)	(0.132)	(0.145)	(0.195)	(0.255)
D_OECD_By=1	0.1344**	0.1376*	0.0472	0.0504	0.2377*	0.2630
	(0.066)	(0.071)	(0.085)	(0.091)	(0.138)	(0.169)
Sample	Full	Full (orig)	Services	Services (orig)	Manufacturing	Manufacturing (orig)
Adjusted R^2						
Observations	1224	845	670	463	318	215

NOTES: *D_OECD_By* = 0 Industry with low digitalization level; *D_OECD_By* = 1 Industry with high digitalization level. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

5.3 Robustness Checks

This Section presents further robustness checks for the relationship between cloud computing adoption and labor productivity. In Table 5.9, the factor inputs in the regressions are based on capital and labor services instead of capital stocks and hours worked.[16] The results are qualitatively the same. As before, the regressions show only a significant positive relationship in the manufacturing sector.

Table 5.9: Dependent Variable: Ln(Real Value Added/Labor Services) - Capital and Labor Services

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud	0.0637		0.3290*		-0.0184	
	(0.073)		(0.170)		(0.091)	
Cloud_orig		0.0485		0.3358*		-0.0623
		(0.077)		(0.185)		(0.097)
ln(*LAB_QI*)	-0.0962	-0.0154	-0.0914	0.0165	-0.0374	0.0486
	(0.084)	(0.088)	(0.227)	(0.243)	(0.099)	(0.100)
ln(*CAP_QI*)	0.1426**	0.1131*	0.2680	0.1670	0.1290	0.1111
	(0.068)	(0.066)	(0.183)	(0.193)	(0.087)	(0.085)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample		Manufacturing		Services	
Adjusted R^2	0.077	0.062	0.084	0.054	0.115	0.115
Observations	1171	825	298	208	645	454

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

In Table 5.10, we vary the way we include cloud computing in our regressions. In columns (1) to (4) we also include the squared term of cloud computing adoption into the regression to test for possible diminishing returns. We mostly see negative coefficients for the squared term (*Cloud x Cloud*) especially

---

[16] See e.g. O'Mahony and Timmer (2009) for a definition and the advantages of capital and labor services especially in the context of ICT capital.

in the manufacturing sector, however without being significant. So there is no clear empirical evidence on diminishing returns. But we have to keep in mind that the number of observation in the manufacturing sector is rather low, so every additional regressor might be costly. The specifications for the full sample with $ln(Cloud)$ instead of $Cloud$ (Columns 5 and 6) are also insignificant.

Table 5.10: Dependent Variable: Ln(Real Value Added/Hours Worked) - Robustness Checks Regarding the Cloud Computing Variable

	(1)	(2)	(3)	(4)	(5)	(6)
$Cloud$	0.0426		0.4442*			
	(0.113)		(0.259)			
$Cloud \times Cloud$	0.0011		-0.2325			
	(0.104)		(0.310)			
$Cloud\_orig$		-0.0148		0.4738		
		(0.123)		(0.324)		
$Cloud\_orig \times Cloud\_orig$		0.0564		-0.2016		
		(0.116)		(0.387)		
$ln(Cloud)$					0.0042	
					(0.017)	
$ln(Cloud\_orig)$						-0.0034
						(0.018)
$ln(Hours)$	-0.0223	0.0537	-0.0200	0.0959	-0.0174	0.0637
	(0.080)	(0.085)	(0.237)	(0.249)	(0.080)	(0.084)
$ln(Kq\_GFCF)$	0.1353*	0.0935	0.3053	0.1964	0.1338*	0.0903
	(0.071)	(0.073)	(0.232)	(0.248)	(0.072)	(0.074)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample		Manufacturing		Full Sample	
Adjusted R^2	0.110	0.091	0.146	0.103	0.110	0.091
Observations	1224	845	318	215	1224	845

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Furthermore, we also investigate whether the relationship between cloud adoption and labor productivity is different for more advanced cloud technologies. Table A.8 in the Appendix presents the results for the adoption of advanced cloud technologies ($Cloud\_HIGH$ - accounting software applications, CRM software and computing power). We do not find any statistically significant relationship neither in the full sample nor in the manufacturing or the services subsample. This however might be related to the even smaller number observations for the regressions with $Cloud\_HIGH$ compare to our main speciation. Instead of investigating the relationship between the usage of cloud computing respectively advanced cloud services and labor productivity, Table A.10 provides results for the regressions for each and every single cloud component in the manufacturing sector. We do find a positive and statistically significant relationship between cloud usage and labor productivity for e-mail, office software, storage of files and databases.

5.4 Limitations

Despite providing some interesting (mostly descriptive) insights, the paper has some limitations. They are predominately driven by the data available for our analysis. One major drawback is the fact that the Eurostat ICT data only provide information about the share of cloud computing adoption per industry but not about the intensity of use (i.e. data on cloud computing expenditures). There is a paper by Ker (2021) which tries to circumvent this issues based on Supply-Use Tables but has rather strong assumptions. Another data issue limiting the analysis are aggregated industries (e.g. just combined values for C27-C28) for the Eurostat ICT data on cloud computing adoption. Related to that is the fact that the overlap between the Eurostat ICT EUKLEMS – INTANProd database (especially in the manufacturing sector) is not very good, reducing the number of observations available in our regressions. In addition, for some industries in certain countries, there is no information on cloud adoption due to confidentiality or quality issues. Due to the rather limited number of observations combined with the lack of a good external instrument [17], we are only able to present controlled correlations and do not claim any causal relationship.

6 Conclusions

The analysis is based on a combination of the EUKLEMS – INTANProd database (Bontadini et al., 2023) and the Eurostat ICT Survey on ICT Usage and E-Commerce in Enterprises of the years 2014 to 2020 for 19 industries and 17 European countries. In general, we do not find evidence that cloud adoption is a substitution for own ICT investments. However, we do find a substitution pattern for investments in IT Hardware. This is especially true in the service sector. Apart from the question on whether cloud services are substitutes or complements for own ICT investments, we also investigate whether the adoption of cloud computing services is indeed economically beneficial. Again, as before with the question on substitutes or complements, we do not find any general pattern for the relationship between cloud adoption and industry-level labor productivity based on augmented Cobb-Douglas production function regressions. However, confirming previous research at the firm level, we do find a positive relationship between cloud adoption and industry level labor productivity only in the manufacturing sector as in Gal et al. (2019) and Duso and Schiersch (2022). Another interesting result is the fact that we do not find any significant effect for advanced cloud computing. This could however be related to the even smaller number of observations with this type of measure for cloud adoption.

Overall, even though public cloud computing services are now playing an important role in the IT ecosystem of firms, research on the causal impact of cloud computing on economic outcomes is still challenging. This is mainly driven by the availability of reliable time series data on cloud adoption and especially spending at a much more disaggregated level. Methodological improvements like the method to recursively calculate cloud expenditures based on existing statistics as outlined in Ker (2021) and the recently collected very detailed survey data from Annual Business Survey (ABS) technology module for the US (Zolas et al., 2020) are a step into the right direction.

---

[17] See e.g. Graetz and Michaels (2018)

References

Baer, A., Lee, K. and Tebrake, J. (2020), Accounting for cloud computing in the national accounts, IMF Working Paper WP/20/127, International Monetary Fund. Washington.

Benlian, A. and Hess, T. (2011), 'Opportunities and risks of software-as-a-service: Findings from a survey of it executives', *Decision Support Systems* **52**(1), 232–246.

Bertschek, I., Briglauer, W., Hüschelrath, K., Kauf, B. and Niebel, T. (2015), 'The economic impacts of telecommunications networks and broadband internet: A survey', *Review of Network Economics* **14**(4), 201–227.

Bertschek, I. and Niebel, T. (2016), 'Mobile and more productive? firm-level evidence on the productivity effects of mobile internet use', *Telecommunications Policy* **40**(9), 888–898.

Bloom, N. and Pierri, N. (2018), 'Cloud computing is helping smaller, newer firms compete', *Harvard Business Review* . https://hbr.org/2018/08/research-cloud-computing-is-helping-smaller-newer-firms-compete.

Bontadini, F., Corrado, C., Haskel, J., Iommi, M. and Jona-Lasinio, C. (2023), 'EUKLEMS & INTANProd: industry productivity accounts with intangibles - Sources of growth and productivity trends: methods and main measurement challenges'. `https://euklems-intanprod-llee.luiss.it/wp-content/uploads/2023/02/EUKLEMS_INTANProd_D2.3.1.pdf`.

Borowiecki, M., Pareliussen, J., Glocker, D., Kim, E. J., Polder, M. and Rud, I. (2021), The impact of digitalisation on productivity: Firm-level evidence from the netherlands, OECD Economics Department Working Papers 1680, OECD Publishing, Paris.

Brynjolfsson, E. and McAfee, A. (2014), *The Second Machine Age: Work, Progress and Properity in a Time of Brilliant Technologies*, W.W. Norton and Company.

Byrne, D. and Corrado, C. (2017), 'Ict services and their prices: What do they tell us about productivity and technology?', *International Productivity Monitor* **33**, 150–186.

Byrne, D., Corrado, C. and Sichel, D. (2021), The Rise of Cloud Computing: Minding Your Ps, Qs and Ks, *in* 'Measuring and Accounting for Innovation in the Twenty-First Century', NBER Chapters, National Bureau of Economic Research, Inc, pp. 519–551.
URL: *https://ideas.repec.org/h/nbr/nberch/13899.html*

Byrne, D., Corrado, C. and Sichel, D. E. (2018), The rise of cloud computing: minding your p's, q's and k's, Working Paper 25188, National Bureau of Economic Research.

Calvino, F., Criscuolo, C., Marcolin, L. and Squicciarini, M. (2018), 'A taxonomy of digital intensive sectors', *OECD Science, Technology and Industry Working Papers* **2018/14**.

Candel Haug, K., Kretschmer, T. and Strobel, T. (2016), 'Cloud adaptiveness within industry sectors – measurement and observations', *Telecommunications Policy* **40**(4), 291–306.

Cardona, M., Kretschmer, T. and Strobel, T. (2013), 'ICT and Productivity: Conclusions from the Empirical Literature', *Information Economics and Policy* **25**(3), 109–125.

Cette, G., Lopez, J., Presidente, G. and Spiezia, V. (2019), 'Measuring 'indirect' investments in ict in oecd countries', *Economics of Innovation and New Technology* **28**(4), 348–364.

Cho, J., DeStefano, T., Kim, H., Kim, I. and Paik, J. H. (2023), 'What's driving the diffusion of next-generation digital technologies?', *Technovation* **119**, 102477.

Corrado, C., Haskel, J., Iommi, M. and Jona-Lasinio, C. (2022), The value of data in digital-based business models. measurement and economic policy implications, OECD Economics Department Working Papers 1723, OECD Publishing, Paris.

Coyle, D. and Hampton, L. (2024), '21st century progress in computing', *Telecommunications Policy* **48**(1), 102649.

Coyle, D. and Nguyen, D. (2018), Cloud Computing and National Accounting, Economic Statistics Centre of Excellence (ESCoE) Discussion Papers ESCoE DP-2018-19, Economic Statistics Centre of Excellence (ESCoE).
URL: *https://ideas.repec.org/p/nsr/escoed/escoe-dp-2018-19.html*

Coyle, D. and Nguyen, D. (2019), 'Cloud computing, cross-border data flows and new challenges for measurement in economics', *National Institute Economic Review* **249**(1), 30–38.

DeStefano, T., Kneller, R. and Timmis, J. (2023), 'Cloud Computing and Firm Growth', *The Review of Economics and Statistics* pp. 1–47.
URL: *https://doi.org/10.1162/rest_a_01393*

Duso, T. and Schiersch, A. (2022), Let's Switch to the Cloud: Cloud Adaption and Its Effect on IT Investment and Productivity, Discussion Papers of DIW Berlin 2017, DIW Berlin, German Institute for Economic Research.
URL: *https://ideas.repec.org/p/diw/diwwpp/dp2017.html*

Fernald, J. G., Inklaar, R. and Ruzic, D. (2023), The productivity slowdown in advanced economies: Common shocks or common trends?, Technical Report 2023-07, Federal Reserve Bank of San Francisco Working Paper Series.

Gal, P., Nicoletti, G., Renault, T., Sorbe, S. and Timiliotis, C. (2019), Digitalisation and productivity: In search of the holy grail – firm-level empirical evidence from eu countries, OECD Economics Department Working Papers 1533, OECD Publishing, Paris.

Gouma, R. and Inklaar, R. (2023), 'Capital measurement and productivity growth across international databases', *International Productivity Monitor* **44**, 67–88.

Graetz, G. and Michaels, G. (2018), 'Robots at work', *Review of Economics and Statistics* **100**(5), 753–768.

Haucap, J., Fritz, D. and Thorwarth, S. (2022), The economic impact of cloud computing in europe, Technical report, DICE Consult.
URL: *https://www.europeancloudalliance.com/wp-content/uploads/2022/11/Cloud-Computing-in-Europe-fin.pdf*

Inklaar, R., Jäger, K., O'Mahony, M. and van Ark, B. (2020), European Productivity in the Digital Age: Evidence From EU KLEMS, *in* 'Measuring Economic Growth and Productivity', Elsevier, pp. 75–94.

Jin, W. and McElheran, K. (2017), 'Economies before scale: survival and performance of young plants in the age of cloud computing', *Rotman School of Management working paper* (3112901).

Katz, R. and Jung, J. (2024), 'Economic spillovers from cloud computing: evidence from oecd countries', *Information Technology for Development* **0**(0), 1–22.
URL: *https://doi.org/10.1080/02681102.2023.2292108*

Ker, D. (2021), Measuring cloud services use by businesses, OECD Digital Economy Papers 304, OECD Publishing, Paris. `https://doi.org/10.1787/71a0eb69-en`.

KPMG (2022), Cloud-Monitor 2022. Das Potenzial von der Kosteneffizienz bis zur Energieeffizienz, Technical report, KPMG, Berlin.
URL: *https://home.kpmg/de/de/home/themen/2022/06/cloud-monitor-2022.html*

Nicoletti, G., von Rueden, C. and Andrews, D. (2020), 'Digital technology diffusion: A matter of capabilities, incentives or both?', *European Economic Review* **128**, 103513.

OECD (2014), Cloud computing: The concept, impacts and the role of government policy, OECD Digital Economy Papers 240, OECD Publishing, Paris.

O'Mahony, M. and Timmer, M. (2009), 'Output, Input and Productivity Measures at the Industry Level: The EU KLEMS Database', *Economic Journal* **119**(538), F374–F403.

Reinsdorf, M. (2021), Measuring cloud computing in macroeconomic statistics, Technical report, Issue paper prepared for 17th Meeting of the United Nations Statistics Division Advisory Expert Group on National Accounts,15, 16 and 19 November 2021. `https://unstats.un.org/unsd/nationalaccount/aeg/2021/M17/M17_7_2_DZ8_Cloud_Computing.pdf`.

Romanko, O. (2021), Digital opportunity: How cloud computing changes the shape of the uk economy, Technical report, Paper prepared for the 36th IARIW Virtual General Conference August 23-27, 2021. `https://iariw.org/wp-content/uploads/2021/07/Romanko_Paper.pdf`.

Statista (2022), Cloud computing market size in europe from 2016 to 2027, by segment, Technical report. Accessed 29th November 2022.
URL: *https://www.statista.com/forecasts/1235161/europe-cloud-computing-market-size-by-segment*

Van Ark, B., de Vries, K. and Erumban, A. (2024), 'Are intangibles running out of steam?', *International Productivity Monitor* **46**, 38–59.

Zolas, N., Kroff, Z., Brynjolfsson, E., McElheran, K., Beede, D. N., Buffington, C., Goldschlag, N., Foster, L. and Dinlersoz, E. (2020), Advanced technologies adoption and use by u.s. firms: Evidence from the annual business survey, NBER Working Paper Series 28290, National Bureau of Economic Research.

A Appendix

A.1 Cloud Computing and Displacement of IT-Workers

Table A.1 provides a minimalist version of a labor demand equation for IT specialists. The dependent variable is the average share of employed IT specialists in total employment by industry. Interestingly, we see a positive and statistically significant relationship for some regressions depending on the sample and the specification of the cloud adoption variable. So switching to the cloud does not seem to negatively affect in-house IT employment. However, these results might be driven by a major limitation of our data, which do not provide any information on the wages of the employed IT specialists.

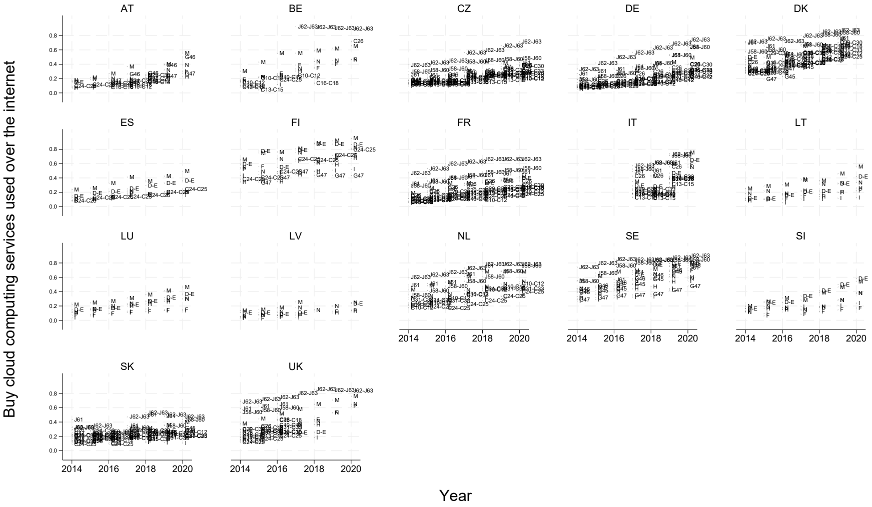
Table A.1: Dependent Variable: Share of Employed ICT/IT Specialists

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud	0.0684**		0.0730		0.0402	
	(0.030)		(0.052)		(0.043)	
Cloud_orig		0.0693**		0.1284**		0.0309
		(0.034)		(0.061)		(0.049)
$ln(Kq\_ICT)$	0.0098	0.0070	0.0139	0.0221	0.0097	0.0078
	(0.009)	(0.009)	(0.022)	(0.025)	(0.013)	(0.013)
$ln(Kq\_NICT)$	-0.0087	-0.0031	-0.0563	-0.0439	-0.0230	-0.0261
	(0.023)	(0.025)	(0.083)	(0.104)	(0.027)	(0.026)
$ln(Hours)$	-0.0401	-0.0358	-0.0948	-0.0890	-0.0119	-0.0151
	(0.030)	(0.032)	(0.107)	(0.128)	(0.034)	(0.035)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample	Full Sample	Manufacturing	Manufacturing	Services	Services
Adjusted R^2	0.016	0.014	0.011	0.022	0.009	0.006
Observations	1198	833	305	203	661	463

NOTES: *Cloud*: with interpolation, *Cloud_orig*: without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

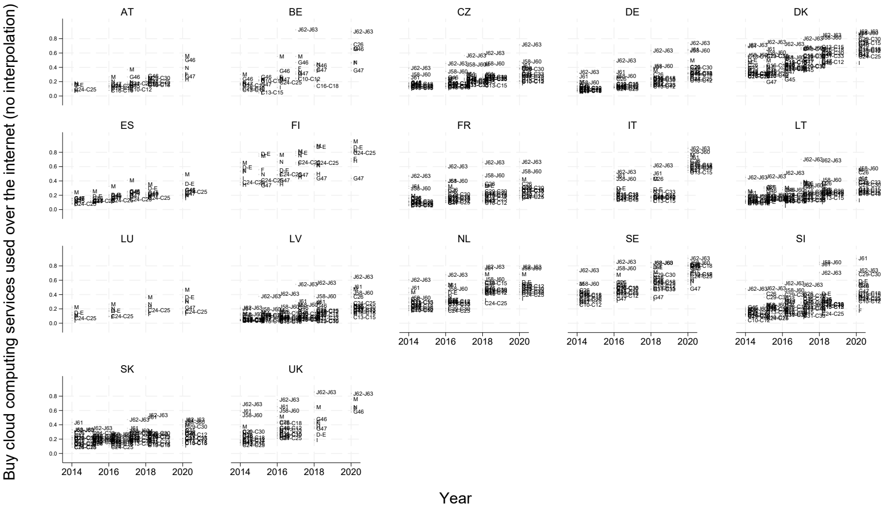
A.2 Additional Graphs

Figure A.1: Share of Cloud Usage by Country/Year/Industry - With Interpolation - Estimation Sample



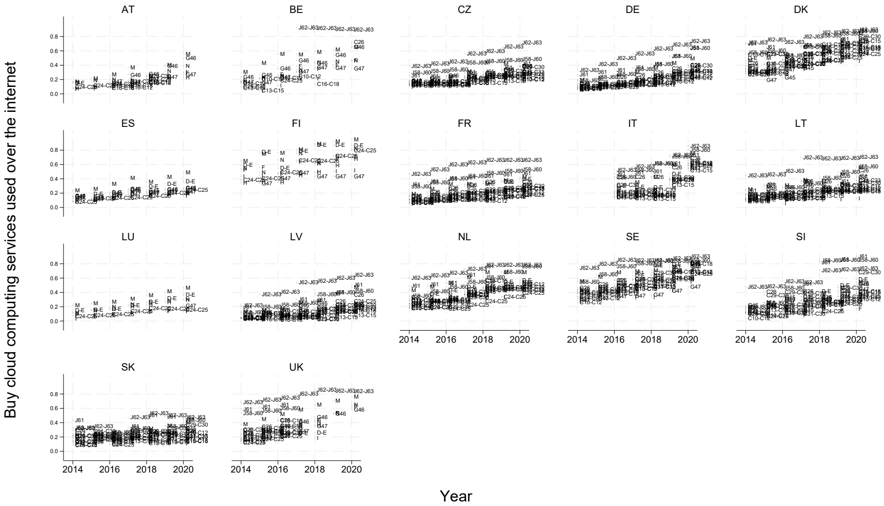
Source: Eurostat Community survey on ICT usage and e-commerce in enterprises.

Figure A.2: Share of Cloud Usage by Country/Year/Industry - Full Sample



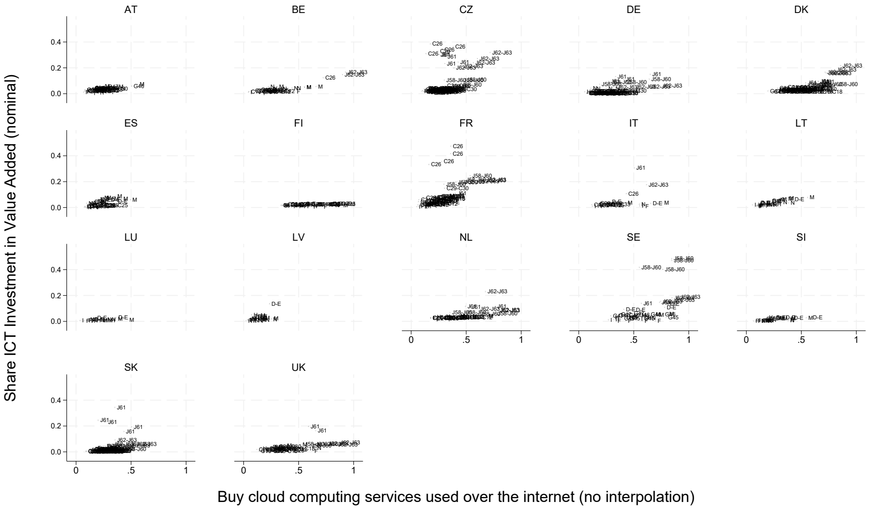
Source: Eurostat Community survey on ICT usage and e-commerce in enterprises.

Figure A.3: Share of Cloud Usage by Country/Year/Industry - With Interpolation - Full Sample



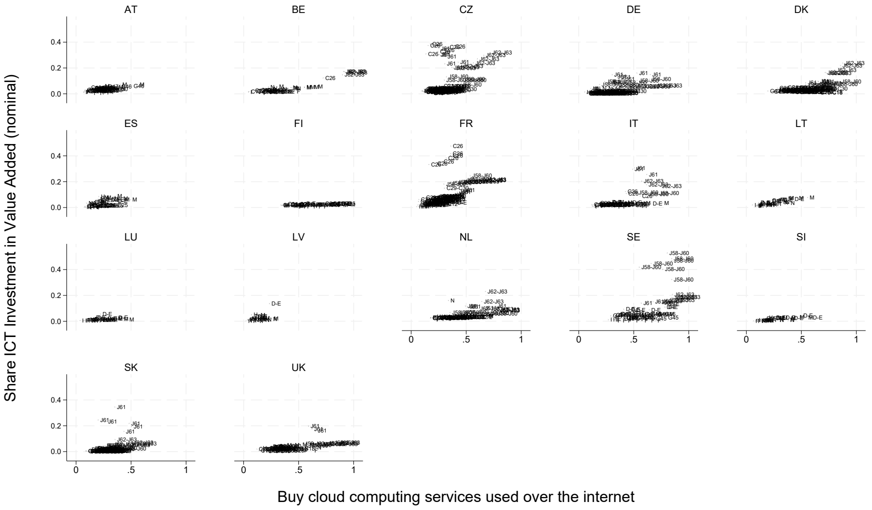
Source: Eurostat Community survey on ICT usage and e-commerce in enterprises.

Figure A.4: Share of ICT Investment in Value Added and Cloud Usage by Country - Estimation Sample



Source: EUKLEMS & INTANProd - Release 2023 and Eurostat ICT survey.

Figure A.5: Share of ICT Investment in Value Added and Cloud Usage by Country - With Interpolation - Estimation Sample



Source: EUKLEMS & INTANProd - Release 2023 and Eurostat ICT survey.

A.3 Additional Tables

Table A.2: List of variables

$Cloud$	Buy cloud computing services
$Cloud\_orig$	Buy cloud computing services (no interpolation)
$Cloud\_HIGH$	Buy high CC services (accounting software, CRM software and computing power)
$Cloud\_HIGH\_orig$	Buy high CC services (accounting software, CRM software and computing power - no interpolation)
VA_Q	Gross value added, volume 2015 ref.prices, volume 2015 ref.prices (millions)
$Hours$	Total hours worked by persons engaged (millions)
$LP(VA\_Q/Hours)$	Labour productivity (gross value added/hours worked)
Iq_ICT	Real ICT investment, volume 2015 ref.prices (millions)
Iq_IT	Computing equipment investment„ volume 2015 ref.prices (millions)
Iq_CT	Communications equipment investment„ volume 2015 ref.prices (millions)
Iq_Soft_DB	Computer software and databases investment„ volume 2015 ref.prices (millions)
Kq_ICT	Real ICT capital stock, volume 2015 ref.prices (millions)
Kq_NICT	Real Non-ICT capital stock, volume 2015 ref.prices (millions)

NOTES: National currencies are converted to 2015 PPP US dollars. SOURCE: Variables 1-4: Eurostat ICT Survey on ICT Usage and E-Commerce in Enterprises (Eurostat ICT); variables 5-13: EUKLEMS – INTANProd database (Bontadini et al., 2023).

Table A.3: Distribution of Industries and Countries - Estimation Sample

	AT	BE	CZ	DE	DK	ES	FI	FR	IT	LT	LU	LV	NL	SE	SI	SK	UK	Total
C10-C12	3	4	7	7	6	0	0	7	3	0	0	0	7	0	0	7	3	54
C13-C15	0	2	7	7	0	0	0	7	3	0	0	0	0	0	0	2	3	31
C16-C18	3	1	7	7	6	0	0	7	3	0	0	0	2	0	0	0	3	39
C24-C25	5	1	7	7	6	7	7	7	3	0	0	0	7	0	0	7	3	67
C26	0	1	7	7	6	0	0	7	3	0	0	0	0	0	0	7	3	41
C29-C30	1	1	7	7	6	0	0	7	2	0	0	0	0	0	0	5	3	39
C31-C33	0	0	7	7	6	0	0	7	3	0	0	0	7	0	0	7	3	47
D-E	1	0	7	7	6	7	7	7	4	7	7	5	0	7	7	7	5	91
F	7	7	7	7	6	6	7	7	4	7	7	6	7	7	7	7	7	113
G45	2	0	7	0	5	0	0	0	0	0	0	0	0	7	0	7	0	28
G46	5	0	7	0	6	0	0	0	0	0	0	0	0	7	0	7	0	32
G47	5	0	7	0	6	0	6	0	0	0	0	0	0	7	0	7	0	38
H	7	4	7	7	6	6	7	7	4	7	7	6	7	7	7	7	5	108
I	5	5	7	7	6	7	7	7	4	7	7	4	7	7	7	7	5	106
J58-J60	0	0	7	7	6	0	0	7	3	0	0	0	7	7	0	7	3	54
J61	0	0	7	7	6	0	0	7	3	0	0	0	5	5	0	6	3	49
J62-J63	0	4	7	7	6	0	0	7	3	0	0	0	7	7	0	7	7	62
M	7	7	7	7	6	7	7	7	4	7	7	4	7	7	7	7	7	112
N	7	7	7	7	6	6	7	7	4	7	7	7	7	7	7	6	7	113
Total	58	44	133	112	107	46	55	112	53	42	42	32	77	82	42	117	70	1224

Table A.4: Cloud Computing Adoption - Estimation Sample

	N	Mean	Median	SD	Min	Max
$Cloud$	1224	.32	.27	.2	.021	.95
$Cloud\_HIGH$	1113	.2	.15	.16	.0088	.83
$Cloud\_orig$	845	.31	.25	.19	.021	.95
$Cloud\_HIGH\_orig$	798	.19	.14	.15	.0088	.83
$LP(VA\_Q/Hours)$	1224	58	46	38	13	302
VA_Q	1224	31,762	13,017	44,479	517	243,602
$Hours$	1224	662	256	985	6.1	4,850
Kq_NICT	1224	52,462	18,754	95,592	542	615,393
Kq_ICT	1224	3,678	920	6,910	10	57,209
Iq_ICT	1224	1,306	367	2,370	1.8	20,342
Iq_IT	1224	188	53	445	.61	4,741
Iq_CT	1224	159	31	447	.14	5,176
Iq_Soft_DB	1224	960	234	2,085	.4	19,975

NOTES: Cloud variables with *orig* are based on the raw values from Eurostat ICT survey. All other cloud variables are enriched with linear interpolations.

Table A.5: Relationship Between Cloud Adoption and ICT investment - Manufacturing vs. Services - Without Interpolation - Dependent Variable: Ln(Real IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)
	IT		CT		Soft_DB	
$Cloud\_orig$	-0.2624	-0.8420***	0.1933	-0.4173	0.0636	0.2496
	(0.784)	(0.320)	(0.651)	(0.522)	(0.480)	(0.402)
$ln(Kq\_ICT_{t-1})$	-0.5450**	0.0180	0.1584	0.2269	-0.2721	-0.1121
	(0.244)	(0.232)	(0.191)	(0.255)	(0.284)	(0.166)
$ln(Kq\_NICT_{t-1})$	0.7762	0.5079	-1.0329	0.3197	2.1070**	0.1676
	(0.973)	(0.370)	(0.838)	(0.570)	(0.903)	(0.236)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Manufacturing	Services	Manufacturing	Services	Manufacturing	Services
Adjusted R^2	0.187	0.077	-0.012	0.078	0.270	0.264
Observations	215	463	215	463	215	463

NOTES: IT: computing equipment, CT: communications equipment, $Soft\_DB$: computer software and databases. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.6: Relationship Between Cloud Adoption and ICT investment - High vs Low Digital Intensive Sectors - Without Interpolation - Dependent Variable: Ln(Real ICT/IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ICT		IT		CT		Soft_DB	
$Cloud\_orig$	-0.0543	-0.2293	-1.0275**	-0.2772	-0.5590	0.0568	0.4411	-0.1656
	(0.365)	(0.181)	(0.449)	(0.328)	(0.613)	(0.391)	(0.474)	(0.259)
$ln(Kq\_ICT_{t-1})$	-0.3529	-0.2192	-0.4083	-0.1370	0.0477	0.3250	-0.0559	-0.3468*
	(0.218)	(0.152)	(0.280)	(0.225)	(0.225)	(0.247)	(0.253)	(0.203)
$ln(Kq\_NICT_{t-1})$	1.0460	0.5881**	-0.3174	0.6532*	0.4240	0.1730	1.6249	0.4906*
	(0.912)	(0.265)	(0.935)	(0.359)	(0.975)	(0.545)	(1.028)	(0.286)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Low	High	Low	High	Low	High	Low	High
Adjusted R^2	0.241	0.326	0.124	0.098	0.074	0.038	0.205	0.321
Observations	396	449	396	449	396	449	396	449

NOTES: *IT*: computing equipment, *CT*: communications equipment, $Soft\_DB$: compute software and databases. Digital intensity (High vs Low) based on the taxonomy from Calvino et al. (2018). Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.7: Relationship Between Cloud Adoption and ICT investment - High vs Low Digital Intensive Service Sectors - Dependent Variable: Ln(Real ICT/IT/CT/Soft_DB Investment)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ICT		IT		CT		Soft_DB	
$Cloud$	0.0464	-0.3140	-1.0340*	-0.1422	-0.8580	0.0687	0.5332	-0.3490
	(0.526)	(0.216)	(0.550)	(0.387)	(0.992)	(0.393)	(0.661)	(0.311)
$ln(Kq\_ICT_{t-1})$	-0.2563	-0.0316	-0.0233	-0.0237	0.2047	0.2356	-0.0626	-0.1228
	(0.252)	(0.125)	(0.276)	(0.207)	(0.351)	(0.246)	(0.235)	(0.165)
$ln(Kq\_NICT_{t-1})$	-0.5256	0.1624	-0.7487	0.6617*	1.1505	0.4691	-0.7331	0.0059
	(0.742)	(0.379)	(0.769)	(0.351)	(2.059)	(0.499)	(1.149)	(0.376)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Low	High	Low	High	Low	High	Low	High
Adjusted R^2	0.256	0.278	0.067	0.020	0.133	0.098	0.238	0.321
Observations	214	456	214	456	214	456	214	456

NOTES: *IT*: computing equipment, *CT*: communications equipment, $Soft\_DB$: compute software and databases. Digital intensity (High vs Low) based on the taxonomy from Calvino et al. (2018). Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.8: Dependent Variable: Ln(Real Value Added/Hours Worked)

	(1)	(2)	(3)	(4)	(5)	(6)
$Cloud\_HIGH$	-0.0153		0.1903		-0.0467	
	(0.067)		(0.201)		(0.087)	
$Cloud\_HIGH\_orig$		-0.0348		0.2129		-0.1056
		(0.075)		(0.265)		(0.098)
$ln(Hours)$	-0.0180	0.0507	-0.0713	0.0422	0.0350	0.1036
	(0.085)	(0.090)	(0.290)	(0.314)	(0.092)	(0.097)
$ln(Kq\_GFCF)$	0.1458**	0.1318*	0.5222*	0.3863	0.1256	0.1229
	(0.073)	(0.077)	(0.291)	(0.307)	(0.088)	(0.095)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full Sample		Manufacturing		Services	
Adjusted R^2	0.106	0.094	0.107	0.052	0.143	0.149
Observations	1113	798	274	195	616	442

NOTES: $Cloud\_HIGH$: Advanced cloud with interpolation, $Cloud\_HIGH\_org$: Advanced cloud without interpolation. Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.9: Dependent Variable: Ln(Real Value Added/Hours Worked) - Manufacturing Sector - Different Levels of Cloud Sophistication

	(1)	(2)	(3)	(4)
$Cloud$	0.2644*			
	(0.143)			
$Cloud\_LOW$		0.4064		
		(0.248)		
$Cloud\_MEDIUM$			0.5065*	
			(0.301)	
$Cloud\_HIGH$				0.1903
				(0.201)
$ln(Hours)$	-0.0545	-0.0205	-0.0504	-0.0713
	(0.235)	(0.276)	(0.260)	(0.290)
$ln(Kq\_GFCF)$	0.3535	0.3989	0.4244	0.5222*
	(0.232)	(0.272)	(0.267)	(0.291)
Year DVs	Yes	Yes	Yes	Yes
Sample	Manufacturing			
Adjusted R^2	0.145	0.116	0.146	0.107
Observations	318	274	270	274

NOTES: $Cloud\_LOW$: Buy only low CC services (e-mail, office software, storage of files); $Cloud\_MEDIUM$: Buy only medium CC services (e-mail, office software, storage of files, hosting of the enterprise's database); $CLOUD\_HIGH$: Buy high CC services (accounting software applications, CRM software, computing power). Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.10: Dependent Variable: Ln(Real Value Added/Hours Worked) - Different Cloud Components - Manufacturing Sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Cloud : e-mail	0.3188*						
	(0.164)						
Cloud : office software		0.3489**					
		(0.162)					
Cloud : storage of files			0.3625*				
			(0.183)				
Cloud : computing power				0.1741			
				(0.267)			
Cloud : CRM software					0.1113		
					(0.252)		
Cloud : database						0.3061*	
						(0.180)	
Cloud : finance or accounting software							0.1360
							(0.242)
$ln(Hours)$	-0.1355	0.0028	-0.0995	-0.0152	-0.0645	-0.0868	-0.0590
	(0.260)	(0.266)	(0.283)	(0.258)	(0.264)	(0.259)	(0.300)
$ln(Kq\_GFCF)$	0.5883**	0.5706**	0.5564**	0.3665	0.3843	0.5708**	0.5016*
	(0.281)	(0.274)	(0.277)	(0.262)	(0.281)	(0.284)	(0.284)
Year DVs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Manufacturing						
Adjusted R^2	0.138	0.136	0.123	0.093	0.096	0.114	0.099
Observations	270	274	271	286	297	281	279

NOTES: Fixed Effects regressions. Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.11: Dependent Variable: Ln(Real Value Added/Hours Worked) - Manufacturing vs Services Sector and High vs Low Digital Intensive Sectors

	(1)	(2)	(3)	(4)	(5)	(6)
Cloud	-0.0088	-0.0015	-0.2262*	-0.1086	0.3220	0.1716
	(0.081)	(0.097)	(0.113)	(0.109)	(0.197)	(0.180)
$ln(Hours)$	0.0361	-0.1636	-0.0282	-0.3452***	-0.4473**	0.1878
	(0.098)	(0.122)	(0.144)	(0.122)	(0.208)	(0.272)
$ln(Kq\_GFCF)$	-0.1341	0.1553*	-0.0969	0.1356	-0.0296	0.5125*
	(0.148)	(0.082)	(0.390)	(0.096)	(0.243)	(0.293)
Sample	Full Low	Full High	Serv Low	Serv High	Manu Low	Manu High
Adjusted R^2	0.055	0.235	0.255	0.311	0.182	0.185
Observations	570	654	214	456	152	166

NOTES: Clustered standard errors in parentheses. * 0.10 ** 0.05 *** 0.01. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.