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Cloud Computing and Firm Growth

Abstract

Cloud computing enables a shift in the costs of ICT adoption from investment in fixed capital to pay-on-demand services allowing firms to scale and reorganize. Using new firm-level data we examine the impact of cloud on firm growth, using zip-code-level instruments of the timing of high-speed fiber availability and speeds. Cloud leads to the growth of employment and revenue for young firms, but they become concentrated in fewer establishments. For incumbents, we find smaller scale effects but dispersed activity through closing establishments and moving employment farther from the headquarters. Moreover, cloud adoption leads to worker relocation across establishments within firms.

JEL-Codes: J230, J240, L200, O330.

Keywords: cloud, digital, productivity, firms.

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Introduction

Over the last decade, a fundamental shift has occurred in the manner by which firms access digital technologies. Traditionally, the acquisition of information and communication technology (ICT) required businesses to make considerable upfront, sunk investments in hardware infrastructure and software and to maintain large IT departments. Now, alternatively, firms acquire their storage, processing and software needs as a service through what is typically referred to as "cloud computing" (Van Ark, 2016; OECD, 2015). Cloud providers offer such services "on demand" throughout the firm via "pay as you go" subscriptions. Purchased in this way IT shifts to a largely variable cost, which it has been suggested, has led to changes in firm behavior that go beyond simply acting as a substitute means of accessing IT (Iansiti and Richards, 2011; OECD, 2015; OECD, 2014).

The growth in this new way of accessing ICT has been rapid. Amazon Web Services was first introduced in 2006 and two years later released further service upgrades allowing for greater capacity in storage and processing power. From 2010, more providers entered the market resulting in increased competition and considerable declines in price (Barr, 2009a; Barr, 2009b). By 2016, 30% of firms used cloud across the OECD, with expenditure on cloud services representing 25% of firms' IT budgets (Eurostat, 2018; Deloitte, 2017).

Understanding the extent to which cloud impacts firm performance is particularly relevant in light of evidence linking ICT to the recent slowdown of business dynamism, rising industry concentration and sluggish aggregate productivity growth (Crafts and Mills, 2020; Bajger et al 2020; Decker et al., 2016; Calvino et al., 2015). Previous empirical evidence suggests that more traditional digital technologies trigger dynamics that benefit a minority of leading frontier firms and widen disparities across firms (Calvino, Criscuolo and Menon, 2016; Brynjolfsson et al., 2008). For example, enterprise resource planning (ERP) technologies enabled large multinationals to co-ordinate and profit from complex and fragmented production networks (OECD and World Bank, 2015). Cloud computing in contrast appears to be more accessible to younger and small entities, potentially levelling the playing field between firms (Bloom and Pierri, 2018).

In this paper we use newly available data for the UK that allows us to determine the timing of adoption of cloud services by firms, along with the types of cloud services used (for email, data and storage, for software etc.). Detailed measures of cloud adoption at the firm-level have not previously been available to researchers on this topic.[2] These data also allow us to explore directly the extent to which cloud adoption impacts firm performance and organization suggested by the literature. Moreover, by exploring how IT investment and computer service expenditures vary with the adoption of cloud technologies, we also provide the first empirical evidence regarding its effects on fixed versus variable IT costs.

Within the paper we build on the existing literature to argue that these economic mechanisms are heterogeneous across young and incumbent firms. It has been claimed that the change in the nature of IT costs to a largely variable cost enables new business models and firm types. Young firms in particular can scale operations quickly without the need for acquiring a mass of ICT assets, labor or establishments, typically referred to as 'scale without mass'.[3] This change is expected to have particularly strong effects for new entrants, since up-front investments can be burdensome for young firms, given their financial constraints due to their

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[2] As we discuss in more detail below, earlier papers instead use IT service expenditures as a proxy for cloud use (Jin and McElheran 2017).

[3] Uber, NetFlix and Airbnb are often held up as examples of the type of business model that have been made possible from cloud computing.

lack of credit history, demand uncertainty and the intangible nature of any intellectual capital. Moreover, by avoiding quasi-irreversible investments in hardware, cloud can allow for greater flexibility and experimentation in the face of such uncertainty, which is key to young firm growth (Decker et al., 2014).

A more open question surrounds the opportunities cloud offers for incumbent firms, who embody organizational models based on previous ways of purchasing and using ICT. Similar to young firms, cloud may reduce fixed costs by reducing the need for incumbents to own the IT capital necessary to cope with peaks in workload and by allowing centralized IT departments to be downscaled (OECD, 2015; OECD, 2014; Economist, 2018). However, the IT literature argues that the benefits from cloud adoption are less clear when legacy software represents important intangible assets for the firm, as these can be difficult to merge with third party provided hardware and platform services (Bommadevara et al., 2018).[4] Further disadvantages may arise if firm-specific knowledge is lost by the shift to external ICT providers, leading to significant problems in the event of service failures (Bommadevara et al. 2018).

For incumbent firms we anticipate that a second mechanism explored in this paper, the mobility offered by decentralized availability of data, processing and software, can have strong effects on the mass of such firms, impacting on their spatial distribution. The reduced costs of accessing information across many devices and locations would typically facilitate greater geographic dispersion of firm activities. This may be because of changes to the spatial organization of the production (Leamer and Storper, 2001; Duranton and Puga, 2005), to management and therefore tasks allocated between plants and their headquarters (Bloom et al.,

[4] For example unless legacy security systems are reconfigured for new security models on cloud environments firms may become vulnerable to cybersecurity threats (Bommadevara et al. 2018).

2014) or because of face-to-face interactions (Gaspar and Glaeser, 1998). Cloud technologies are likely to act primarily on the organization of production, reducing the sequencing and coordination problem of working in teams. Employees can work on tasks simultaneously and have greater freedom in their place and time of work, reducing the use of fixed PCs connected to the internal hardware and software of the firm during standard working hours. Working in the opposite direction are the effects offered by the increased flexibility to scale in response to demand changes. The ability to deliver a new service or product in a short time period comes with risks that require new processes and monitoring to ensure quality and reliability during shorter innovation cycles (McKinsey, 2018). This monitoring and problem solving is more likely to be done by senior managers and therefore to occur at the center of the firm.[5] Which of these geographic effects dominates for cloud adopters is unclear and is therefore assessed in this paper.

We use a number of both traditional and novel measures of firm geographic dispersion within the paper. These include the multi-establishment status of the firms as well as establishment births and deaths. Alongside these we introduce two new measures of geographic concentration.[6] First, we measure the unweighted and weighted average distance between establishments and the firm headquarters (weighted by the share of establishment employment in firm employment). Secondly, we construct a distance-employment covariance term to

[5] Cloud might also encourage the adoption of new working practices, such as hot-desking or flexible work patterns, allowing greater economic activity to occur in a given space. DeStefano, Kneller and Timmis (2019b) equate this to a form of capital-saving technical change and provide empirical evidence in support of this mechanism.

[6] These metrics are adapted from extensive use in the productivity literature, which measures the distribution of employment activity across firms of different productivity (Criscuolo et al. 2014).

measure how employment is distributed across more proximate or more remote establishments. This term reflects whether larger establishments tend to be more distant from the headquarters (a positive covariance), or whether closer establishments are larger (a negative covariance). To track these changes further we then combine our firm level information with data for a random 1% sample of all workers in the UK. This allows us to track more closely the types of workers that are relocated and where to. We are aware of no other study in the IT literature that has previously investigated this point.

A final contribution of the paper is an attempt to address endogeneity concerns for the adoption of cloud using an instrumental variable approach.[7] The paper constructs firm-specific instruments using novel zip-code-level data on the availability and expected speeds of high-speed fiber broadband - a technological prerequisite for adopting the cloud. A stable, high-speed broadband connection is required to allow the large flows of data between the cloud service providers and users (ITU, 2017).[8] The growth of cloud services is a phenomenon that has gone hand-in-hand with the diffusion of high-speed fiber broadband. We are only aware of one other paper using the availability of fiber as an instrumental variable.[9]

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[7] Evidence on the impact of cloud at the firm-level remains sparse and the authors are not aware of previous studies that consider the effect on firm organisation. One of the few firm level empirical papers which examines ICT services is Jin and McElheran (2017). In part this is due to limited data on the use of cloud and the types of services purchased (Bryne et al, 2017; 2018; Brynjolfsson et al, 2017).

[8] An exception is email services which can be accessed with ADSL broadband.

[9] Fabling and Grimes (2016) examine how the diffusion of fiber impact the employment and productivity of New Zealand firms, using proximity to nearby schools as an instrument.

These instruments strongly predict the firm's decision to adopt cloud. Firms with access to fiber and those with shorter cable (local loop) distances[10] to the nearest telephone exchange (enabling faster fiber speeds) are more likely to adopt cloud than those connected to exchanges not yet enabled with fiber or those with fiber access but longer cable distances. Importantly we find that these distance instruments behave in a manner that is closely aligned with the predictions from the telecoms engineering literature. We also take seriously issues surrounding the plausibility of these instruments, which we deal with by a series of sample restrictions and tests of the correlation between the instruments and observable confounders in time periods before fiber becomes available. We also show that the instruments are not correlated with the adoption of other ICT or other E-commerce practices during this time further supporting the validity of the instruments.

To preview the main results of the paper. Firstly, in terms of adoption mechanisms we find that cloud does indeed lead to a switch of IT costs away from fixed to variable costs, although these appear to occur largely through reducing (fixed) IT investment costs rather than by changing variable IT costs. Second, we find strong heterogeneity in the performance and geography effects of cloud. Younger firms that adopt cloud are more likely to grow in employment and sales. They are less likely to become multi-establishment but there are no other geographic impacts. For young firms, cloud adoption is therefore associated with scale and mass in terms of employment and revenue but not geography. For incumbent firms that adopt cloud the employment (and sales) effects are smaller in comparison to young firms. They are also more likely to reorganize, closing establishments and decentralizing activities

[10] We proxy these cable distance with crows flies distance. Using data from telecoms consultancy firms on cable distances shows a correlation between cable and crows flies distances of 0.995.

(employment) farther from the headquarters and in a greater variety of localities. Decomposing the dispersion to the level of the employee, we find that workers in establishments using cloud technologies are significantly more likely to be relocated compared to establishments that have not yet adopted the technology. Taken together cloud appears to have important implications for how young firms grow, and how incumbent firms reorganize.

In considering these questions we build on a small literature on the effects of cloud computing on firms. Bloom and Pierri (2018) find for example, that the adoption of cloud is occurring at a faster rate amongst young and small business entities than for previous IT technologies, while Jin and McElheran (2017) find evidence that purchases of ICT services are related to significantly higher survival and growth among young establishments. This paper also contributes to our understanding of ICT more generally by including both traditional and relatively unexplored dimensions of how firms grow, including measures of firm spatial fragmentation.

This work also contributes to an emerging part of the ICT literature that focuses on the impact of the organization and geography of the firm. Previous work examining the impact of ICT on firm organization find that digital technologies are shown to lower the cost of communication resulting in more hierarchical firm structures (Bloom et al., 2014). Other research demonstrates that processing ICT and communication ICT often push economic activity and decision making in competing directions (Bloom et al., 2014 and Garicano and Heaton, 2010). Focusing on the effects of a specific communication ICT, ADSL broadband, DeStefano, Kneller and Timmis (2018) find that access to broadband led to increased scale of firms through greater employment. Studies focusing on the geography of the firm have examined the link between the diffusion of broadband on regional concentration of innovation, finding evidence of growth in patenting amongst earlier adopters of the internet (Forman et al 2015). More recently, Greenstein et al (2018), provides an overview on the effectiveness of digital technology for establishing new partnerships or collaborations across geographic space.

Most studies consider the impact of earlier ICT technologies such as ADSL broadband, rather than high-speed fiber across countries and firms (Van Gaasbeck,. 2008, Kolko 2012; Grimes et al. 2012 Bertschek et al. 2013, Haller and Lyons 2015; Akerman et al. 2015; DeStefano, Kneller and Timmis 2019a). More recently Fabling and Grimes (2016) use the rollout of fiber to schools in New Zealand. Our approach builds on this by using zip-code level information on the date of fiber enablement alongside information on expected fiber speeds.

The rest of the paper continues as follows. Section 2, provides a brief description on what is cloud and provides preliminary evidence on the mechanisms between investment in IT and cloud adoption. Section 3 discusses the data used in this paper while Section 4 introduces the empirical framework for the analysis. Section 5 presents the main results of the analysis and Section 6 provides some concluding comments.

What is Cloud and how does it differ from traditional ICT?

Cloud computing is a service delivered by third party providers which "*enables ubiquitous, convenient on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*" (US National Institute of Standards and Technology 2011).[11]

According to the IT literature cloud computing is distinct from traditional IT technologies and the outsourcing of IT services. Its storage and data processing capacities are available on

[11] The largest global cloud providers include Amazon Web Services, Microsoft Azure and Google Cloud Platform.

demand, offers rapid scalability and easy network access throughout the firm on standard devices like desktops, laptops and mobile phones (OECD 2014; NIST 2011, Armbrust et al. 2009, and Schubert et al. 2010).[12] This largely negates irreversible upfront commitments as services are purchased instead through short term pay-as-you-go contracts. It is also believed to reduce the need for centralized IT departments and allows workers to access IT infrastructure in many locations (Iansiti and Richards, 2011). However, the transition to the cloud may be more difficult for firms that have made large investments in software in the past.

Data

In this paper we utilize novel firm-level, establishment-level and worker-level data from the Office for National Statistics (ONS), which is the UK Census Bureau equivalent. Basic data on firms such as employment, industry and precise location of the headquarters and its establishments is sourced from the UK business registry – the Business Structure Database (BSD). This provides a complete census of all VAT registered businesses in the UK. We also use this data to create a measure of multi-establishment status of a firm, establishment deaths and establishment births (per firm) and various measures of geographic concentration of the firm that we detail below.[13]

[12] Armbrust et al. (2009) include a reference to Animoto, who following making their service available via Facebook saw a surge in demand necessitating an increase from 50 to 3,500 servers in just 3 days. They argue such scaling would have been impossible with traditional IT purchasing methods.

[13] Number of establishments, establishment deaths and establishment births are all expressed in logs. We add one to the number of establishment deaths and births to avoid dropping zeroes.

Information on cloud adoption is taken from the E-commerce Survey, also conducted by the ONS. The survey was first introduced in the year 2000 and is available annually thereafter. It is a stratified random sample of all firms. The strata are defined by industry and employment, such that larger firms are over-represented. The E-commerce Survey includes questions regarding seven different types of cloud computing. These include hosting the business' databases, storage of files, email, office software (such as word-processing and spreadsheets), finance and accounting software, CRM software and running the business' own software.[14] These questions are asked in 2013 and 2015 only. From these seven questions we construct a binary variable of whether the firm uses any form of cloud computing, although we also report results using these types of cloud technology separately (again, constructed as dummy variables).

To measure outcomes such as sales and labor productivity, along with IT investment and expenditures of computer services, we use information from the Annual Respondent's Database (ARD). Constructed from a mandatory business survey, the ARD is a census of large businesses and a stratified random sample of smaller firms. It covers economic activity in all sectors of the economy aside from agriculture and finance for the period 1997 to 2016. Unfortunately, we do not have comprehensive capital data, which prevents analysis of TFP. The ARD provides information at two levels of aggregation; at the firm-level and the establishment-level. Unique establishment and firm identifiers permit merging with the BSD and E-Commerce surveys.

As we outline in detail below our estimation strategy relies on the adoption of cloud technologies. Alongside the data for 2013 and 2015, to measure pre-cloud adoption firm

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[14] We provide the exact questions in the Appendix.

performance we use data from 2008. This year is the date at which the fiber enablement program was first announced in the UK (which occurred in October 2008) and which we provide more discussion on in the section on fiber rollout. To remove concerns about endogenous location choice, we focus on those firms born before 2008 and therefore had already chosen their location prior to this fiber rollout program.[15] Our results are robust to further excluding firms born in 2007 and 2008.[16]

As discussed above, there are strong reasons to expect that the impacts of cloud may differ between younger and incumbent firms. We explore treatment heterogeneity in our analysis by allowing for separate effects of cloud on new and incumbent firms. We capture this using a dummy variable denoting if a firm was aged 5 years old or younger in 2008. Alongside standard measures of firm performance such as size, labor productivity, entry and exit etc., we also include various measures of the geographic dispersion of firms and introduce two new measures of geographic concentration. Our first measure reflects the number of different local authorities in which a firm's establishments are located. Our second measure reflects the geographic dispersion of employees from the headquarters – specifically a weighted average distance between establishments and their headquarters (weighted by the share of establishment employment in firm employment). We decompose this weighted average distance into two terms – an unweighted average distance and a distance-employment covariance term. The unweighted average distance of establishments from their headquarters, captures how far establishments are located from the headquarters. The covariance term measures how employment is distributed across establishments. Specifically, this term reflects the covariance between establishment distance from the headquarters and establishment employment. A

[15] We provide a fuller discussion on this point in the next section of the paper.

[16] Due to the nature of the rollout program, the sample of firms in our analysis are predominantly in urban settings.

positive covariance, shows that more distant establishments are becoming relatively larger in terms of employment, and a negative covariance shows that establishments closer to the headquarters are becoming larger. This covariance term has been popularized by Olley and Pakes (1996) in productivity decompositions, for analyzing whether more productive firms are typically larger. Since we estimate with firm fixed effects, we capture how the distribution of employment across establishments changes over time.

In order to further decompose firm geographic dispersion, we use employer-employee data from Annual Survey of Hours and Earnings (ASHE).[17] ASHE is a 1% panel of all the workers in the UK derived from HM Revenue and Customs' Pay As You Earn records. Workers can be matched to establishments and firms in the UK and tracked over their employment lifetime, allowing movements within or across firms over time to be measured.[18]

Table 1 provides summary statistics for all firms, young and incumbent firms for all years and then separately for 2013 and 2015 for the aggregate measure of cloud as well as the 7 different types reported in the E-commerce Survey. The data show that around 23% of firms use some form of cloud within the sample period. The figures for individual forms of cloud services, including storage of files (15%), business databases (10%), and email (13%) are lower, indicating that firms typically adopt some but not all types of cloud. In general, the switch over to cloud services has been greater for the types of cloud where service provision is likely to be homogenous such as email, storage of files and some types of software, than for

[17] This data is used by various papers including Bell and Van Reenen (2013) and Aghion et al (2017).

[18] Due to data limitations (we have only a 1% sample of employee jobs) we assess employee movement within/across firms but are not able to examine changes in the distribution of wages or skill compositions.

the types of cloud where the service requirements are more likely to be firm-specific (Bommadevara et al., 2018).[19]

It is also evident from Table 1 that cloud adoption is lower amongst young vs incumbent firms, at least by the end of the time period. For the overall measure, 18% of young firms use some form of cloud, whereas for incumbents it is over 24%. This contrasts with a commonly held view that access to digital technologies via the cloud is particularly attractive for young firms.

Table 1 Summary Statistics of Cloud Adoption

	All firms *(14,390 obs.)*		**Young firms** *(1,872 obs.)*		**Incumbent firms** *(12,518 obs.)*	
Variable	**mean**	**st.dev.**	**mean**	**st.dev.**	**mean**	**st.dev.**
Cloud	0.234	0.424	0.179	0.384	0.243	0.429
Cloud Databases	0.100	0.300	0.088	0.283	0.101	0.302
Cloud Storage of files	0.149	0.356	0.118	0.322	0.154	0.361
Cloud Email	0.126	0.332	0.114	0.318	0.128	0.334
Cloud Office Software	0.085	0.278	0.076	0.266	0.060	0.280
Cloud Finance Software	0.052	0.222	0.054	0.227	0.086	0.280
Cloud CRM	0.071	0.257	0.060	0.237	0.052	0.221
Cloud Processing Own Software	0.059	0.236	0.055	0.227	0.073	0.260

Notes. These present statistics from a balanced panel of observations for comparison of adoption across time for the same set of firms – a subset of our estimation sample of firms. Reflects years 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008

The averages across all years (2008, 2013 and 2015) appear low in part because there is no adoption of this technology within the base year of 2008. To more clearly show the adoption of these different forms of cloud technologies over time we report in Appendix Table A1 their values in 2013 and 2015 separately.[20] By 2013 the rate of cloud adoption is 41%, rising to 47% just two years later. The patterns of growth are similar amongst young and incumbent firms,

[19] We investigate the correlation between the different forms of cloud use in 2013 and 2015 (see Table A4).

[20] To ensure that the statistics in Table 1 relate to adoption rather than changes in the sample of firms we report these summary statistics for a balanced panel of firms.

although we note there are small decreases in adoption by young firms for databases, CRM software and for running its own software.[21]

Mechanism between cloud and traditional IT components

We explore initial evidence on the mechanisms through which cloud adoption impacts firm costs in Table A5 in the Appendix. In regressions 1 and 2 in this table we consider whether cloud adoption leads to a substitution away from IT as a fixed to a variable cost, measured here as IT investment (per employee) and as IT services expenditures in total costs, respectively. The effect on purchases of IT related services will include payments for the use of cloud services to external parties such as Amazon, Google and other providers, as well as other non-cloud costs. The extent to which cloud predicts IT service use is of interest given IT services are used as proxy measure of cloud adoption in the literature.

The results suggest that cloud impacts firms' total average costs by reducing fixed IT costs rather than by changing variable IT costs (see Table A5 in the Appendix). The adoption of cloud is correlated with a significant decline in IT investments per employee by 49% over the sample period.[22] Investments in IT capital and software decline when the firms adopt cloud as one might expect, indicating that cloud does indeed allow for some substitution away from the owning IT equipment. This effect is apparent for both young and incumbent firms, with stronger effects on the latter (50% compared to 36%).

[21] Tables A2 and A3 provide summary statistics on all firm and employee-level variables in the Appendix.

[22] Since the regression is log-linear, -49% is calculated as exp(-0.672)-1, using the estimated coefficient from regression 1 in Table A5 in the Appendix. The same is applied throughout the paper for all log-linear regressions.

In contrast, there appears to be no statistically significant correlation with computer service related expenditures and cloud adoption for both young and incumbent firms.[23] In Table A6 in the Appendix we explore whether there are declines in the share of costs associated with any of the seven different forms of cloud. Here we find computer service costs fall when the firm adopts cloud to host the firms' databases, CRM or host its own software.

Estimation Strategy

This paper relies on an instrumental variable estimation to assess the various dimensions through which cloud computing adoption effects firm growth and organization. Our basic set-up is a fixed effects panel model set out in equation (1). The dependent variable y, refers to a number of firm outcome variables, including employment, sales and sales per worker, but also measures of the concentration of activity, measured by the multi-establishment status, establishment deaths and establishment births (per firm) and the geographic concentration of the firm.

$$y_{it} = \alpha_i + \alpha_t + \beta cloud_{it} + \gamma X_{it} + \boldsymbol{\varepsilon_{it}} \quad (1)$$

Our parameter of interest, $cloud$ is a binary variable that measures the firms' use of any of the different forms of cloud computing services asked in the E-Commerce Survey.[24]

We include firm (α_i) and year (α_t) fixed effects in all our estimations, such that our estimates capture changes in firm outcomes driven by cloud adoption, removing the effect of any time invariant firm- industry- or location-specific confounding factors. X_{it} represents a vector of

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[23] These results for IT investment and for computer service expenditures continue to hold if we use the instrumental variable approach from Section IV. These results are available in Table A18 in the Appendix.

[24] We consider different types of cloud separately in robustness analyses.

controls including firm age, foreign ownership and size measured by the number of establishments.

The instrumental variable regression in equation (2) relies on two instruments to predict firm cloud adoption: access to fiber broadband (lagged one period) signified by $fiber_{it-1}$ and as a proxy for fiber speeds, broadband availability interacted with firm distance from the telephone exchange, $fiber_{it-1} * dist$ (see next section).[25] The fiber enablement variable $fiber_{it-1}$ indicates whether a firm is connected to a part of the telecommunication infrastructure that is enabled with fiber last period signified by $fiber_{it-1} = 1$ or if the firm is connected to a non-enabled exchange $fiber_{it-1} = 0$.[26]

$$cloud_{it} = \alpha + \beta fiber_{it-1} + \beta fiber_{it-1} * dist_i + \gamma X_{it} + \boldsymbol{\varepsilon_{it}} \tag{2}$$

We detail these instruments and their construction next.

Fiber Broadband Instrumental Variables

What is Fiber?

In the UK, fiber is the main source of high-speed broadband. Like its main predecessor, ADSL, it relies heavily on the telephone exchange network, using pre-existing exchange boxes and cabinets to deliver internet services. For this paper we use the mapping of the telephone network used previously by DeStefano et al. (2018), which includes information on the location of all telephone exchanges in the UK (of which there are over 5,600) and of distances between zip-codes (of which there are over 1.7 million) and the exchange they are connected to. To this

[25] These instruments are calculated using the location of the firm headquarters.

[26] Instruments are lagged one year to allow for the adjust time between fiber enablement and cloud adoption.

we add new information on the date of enablement of the exchange for fiber broadband from OFCOM (the UK telecoms regulator).

We consider the most prevalent form of fiber in the UK, fiber to the cabinet (FTTC) uses a fiber optic cable between the exchange box and the cabinet rather than the pre-existing copper cable used by older vintages of broadband. These fiber cables are more efficient in transmitting data offering faster upload and download speeds. For example, on average in the UK, FTTC offers speeds of around 33.4 mbps while ADSL speeds are a maximum of 8.0 mbps (BT Openreach, 2017).[27]

Fiber enablement

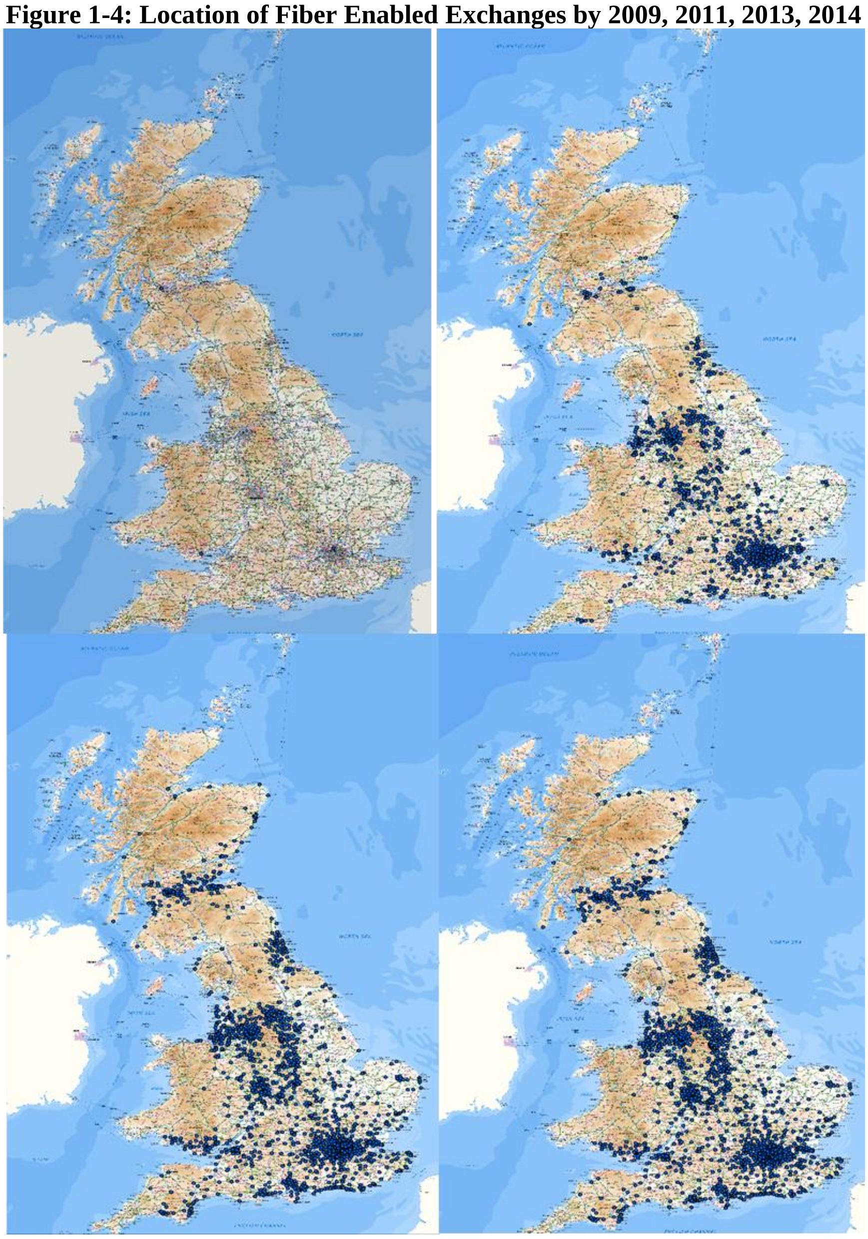
Our first instrument, fiber availability, relies on data detailing the rollout of fiber broadband in the UK. Our dataset contains enablement information from the start of the rollout program, in 2009, to its completion in 2014 covering predominately urban regions of the country (See Figure 1-4). The program accounts for around 30% of all exchanges and 80% of businesses.[28] The rollout was first announced in October 2008, with a pilot phase of 3 exchanges enabled with fiber. These exchanges were enabled in 2009. Following the pilot, BT announced a £2.5bn

[27] A small minority of establishments in the UK have fiber to the premise (FTTP), where the fiber network runs from the exchange, to the local cabinet and on to the premises. While we do not have precise data on locations with FTTP, they represent a small share of UK businesses. Only 0.05% of households and businesses had FTTP during this rollout period (Point Topic, 2014).

[28] During this time, the number of exchanges equipped with fiber increased from 159 exchanges in 2010 to 1627 exchanges by the end of 2014 (see Figures 1-4). Note some rural and local fiber enablement schemes commenced after 2014 which we exclude in our analysis.

program intended to rollout of fiber to cover 66% of the UK homes and businesses by spring 2014.[29]

Figure 1-4: Location of Fiber Enabled Exchanges by 2009, 2011, 2013, 2014



Notes. Points represent the location of fiber enabled exchanges in each year.

[29] We exclude from the sample exchanges in Northern Ireland and Cornwall as these were enabled in a joint-venture with BT, with limited data on exchange enablement dates.

The UK rollout consisted of 11 phases, with the timing determined by a number of factors. Given the size of a national telecommunication infrastructure, the timing of enablement was strongly influenced by supply constraints on telecoms engineers who had to physically activate each exchange and cabinet throughout the network. Parts of the network which had more wear and tear were enabled later as they required additional investment.[30]

Our second instrument exploits the fact that expected fiber speeds decline with distance to the telephone exchange. Broadband is a distance dependent technology, with longer cable distances from the exchange associated with slower internet speeds (Ofcom, 2016). Fiber speeds deteriorate rapidly the greater the cable between the cabinet and the premise for FTTC, with the fastest speeds in very close proximity to the exchange.

Table 2 illustrates the differences in the crow-flies distances to the exchange that we use for firms in our sample. These differences suggest disparities in fiber speed given the distance dependency of the technology. For example, the crow-flies distance between the median firm and their exchange is roughly 1.1 kilometers where the crow-flies distance of the top 25% is around 500 meters and the bottom 75% is roughly 1,800 meters. It is also important to note that crow flies is likely to underestimate the actual distance of the local loop cable running between the premise and the exchange box. [31]

[30] A number of exchanges were enabled much later than planned. For example, Kensington Gardens and Chelsea were initially scheduled to be enabled April 2011, but were only enabled in in February 2013. The enablement was delayed because local residents disliked the proposed color scheme of the fiber cabinets.

[31] This is because cables do not travel in a straight line but can follow local terrain and pre-existing infrastructure.

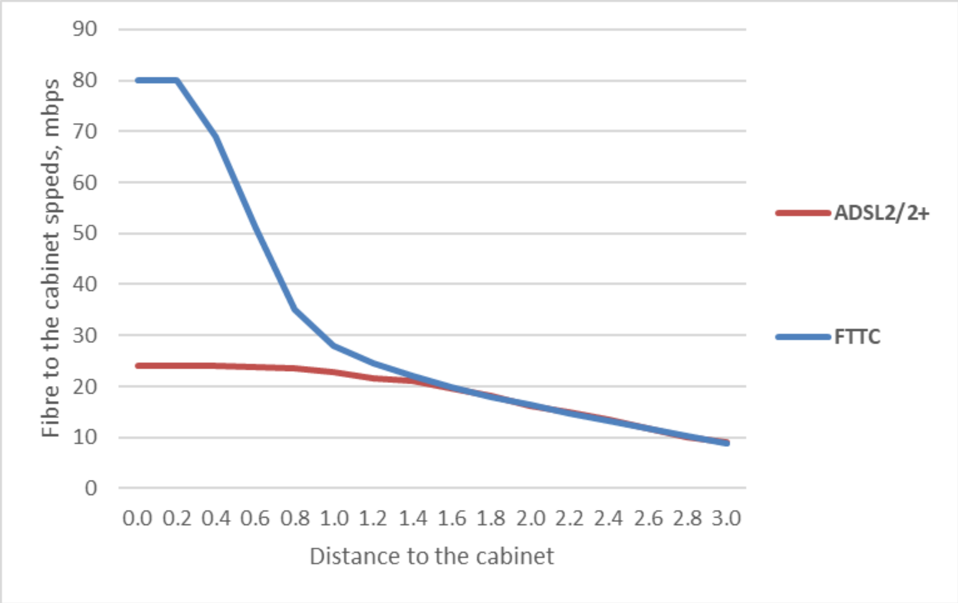
Table 2: Crow-flies distance to the local telephone exchange

Frequency	Crow flies distance (km)
1%	0.057
5%	0.184
10%	0.283
25%	0.547
50%	1.082
75%	1.876
90%	2.773
95%	3.372
99%	4.593
Mean	1.342

FTTC speeds decay far faster than under earlier ADSL broadband, delivered through copper telephone lines, as shown in Figure 5. Based on engineering tests, these figures show that for a cable distance of 2,000 meters from the cabinet, FTTC connections speeds are under a quarter of those were the cable distance is 200 meters of the cabinet, 80 mbps compared to 17 mbps. In practice, firm distance from the cabinet is not a precise threshold for speed deterioration.[32] Therefore, while fiber provides a substantial improvement over the earlier technology (ADSL), only over very short distances within 1000 meters of the cabinet.

[32] Other factors include the width of the cable, the quality of the copper used in the cable and so on. Firms connected by an older and/or thinner cable laid in less optimal terrain with different wear and tear experience speed deterioration at shorter distances than say longer thicker cable in optimal environments.

Figure 5: Fiber to the cabinet connection (FTTC) speeds and distance to the cabinet



Notes. Here we report expected fiber to the cabinet (FTTC) and ADSL broadband speeds by distance from the cabinet and telephone exchange respectively. We do not include FTTC speeds of those farther than 3 kilometers as these are extremely rare (Heath, 2013).

Instrument Validity

The validity of our instruments requires that fiber enablement and distance from the telephone exchange have no effect on our firm performance measures independent of its relationship with cloud. We discuss this issue below and detail how we deal with potential objections through sample restrictions, control variables and tests of robustness.

The cable distance instrument used depends on the location of the firm and of the telephone exchange. The location of the telephone exchanges is based on the pre-existing telephone infrastructure dating back in some cases as far as the 19th century. The main purpose of the telecom network was originally to enable the use of the telephone. Importantly, the use of load coils allowed the quality of phone calls to be maintained as far as 16 kilometers from the telephone exchange (Macassey, 1985). Distance from the exchange was therefore much less of an issue for the telephone technology the network was initially built for.

Given this, it would seem plausible that firms born before the development of fiber broadband did not choose their location relative to the telephone exchange based on a technology that had yet to be invented.[33] As noted in the data section, notwithstanding the above arguments, we minimize any risk associated with the above points by excluding from the sample firms born after 2008. We therefore focus only on firms born before the fiber rollout program was initiated.

While the timing of enablement by British Telecom might be outside of the control of individual firm, the timing of an individual exchange within the network was a commercial decision. Those locations, and firms in those locations that are part of the fiber program, are substantially different to those that are not part of the program. The exchanges that were chosen to be part of the program are typically in urban locations, with a larger agglomeration of households and businesses connected to the exchange. To remove the effects of this issue, for our analyses we *exclude* all firms connected to exchanges outside the BT fiber program that were enabled after 2014, and focus entirely on the timing of enablement of exchanges *within* the BT program. [34]

Another challenge to the exclusion restriction may result from the fact that fiber enablement was targeted initially at urban exchanges. These exchanges are characterized by shorter local loops and are attached to more households, which are features likely to be correlated with

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[33] Cost restrictions and technical aspects prevented BT from digging up parts of the network to move existing copper cables and exchanges closer to certain businesses. Moreover, limited inter-connections to the fiber backbone of the network prevented businesses from switching to a different telephone exchange.

[34] A secondary reason for the choice to end the rollout period in 2014 is that after this date some local fiber schemes began to enable some exchanges outside the BT fiber program – often part of the government-funded Broadband Delivery UK – and so it is not possible to assume those exchanges outside the BT program did not have fiber access in later years.

agglomeration or other geographic factors.[35] Agglomeration may therefore help predict shorter local loop lengths and fiber enablement and be correlated with measures of firm performance.

A final potential challenge to the validity of our cable-distance instrument is based on passive sorting. The locations chosen for telephone exchanges were not random; they were sited to be near to commercial centers and concentrations of residential property and, to aid with the laying of cabling, they were often also located near major road junctions. Plausibly firms may also wish to be close to commercial centers and major road junctions. Therefore, the empirical results may be driven by some unobservable firm characteristic rather than the technology itself.

We note firstly that these concerns are unlikely to be valid in our setting given our sample restrictions. As noted, distance had no bearing on the quality of telephone connections and it would seem plausible that firms born before the fiber rollout did not choose their locations to be close to the telephone exchange. Cost restrictions and technical aspects also prevent the network owners (BT) from digging up the network to move existing cables and exchanges closer to certain premises. Also, a lack of inter-connections of the fiber backbone prevented consumers from switching to a different telephone exchange. Nevertheless, to the extent that these geographic factors or firm characteristics are time invariant, or at least over our 8-year time window, such effects will be captured by the firm fixed effects we include in the regression model.

These fixed effects do not remove the possibility that fiber enablement was targeted at telephone exchanges where firms were expected to grow quickly in the future however. To

[35] Agglomerations of businesses are typically more productive (Combes et al., 2012), and more likely to use new technologies, such as ICT, and possess greater management skills (Glaeser and Resseger, 2010; Puga, 2010).

consider the plausibility of this argument, we exploit pre-enablement data to test for a correlation between ex-ante observable measures of firm performance (changes between 2007 and 2008) and future fiber enablement. If fiber enablement was being used as some part of regional policy to reinforce or rectify regional economic differences, then we would expect to strong correlations with these ex-ante characteristics.

As the evidence from Table 3 suggests, instead we find that there are no significant correlations with the instruments timing of fiber enablement and firm distance to the exchange on ex-ante firm performance measures including changes in sales, employment or sales per workers. Finally, we can find no evidence that the exchanges which were enabled as part of the fiber program had short local loop distances. These results are consistent with an interpretation that our instruments are valid.

Table 3: Effects of fiber enablement and exchange distance on ex-ante firm characteristics

Regression No.	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Year of fiber enablement			**Exchange distance**		
ΔLog Sales	-0.025			-0.035		
	(0.035)			(0.027)		
ΔLog employment		-0.028			-0.007	
		(0.066)			(0.058)	
ΔLog sales per worker			-0.018			-0.032
			(0.032)			(0.026)
ΔMulti-establishment	0.120	0.103	0.109	-0.063	-0.049	-0.084
	(0.106)	(0.112)	(0.106)	(0.080)	(0.084)	(0.081)
ΔForeign owned	0.129	0.142	0.128	0.017	0.015	0.016
	(0.126)	(0.126)	(0.126)	(0.075)	(0.075)	(0.075)
ΔAge	0.007	0.012	0.007	0.000	-0.001	0.000
	(0.009)	(0.009)	(0.009)	(0.007)	(0.006)	(0.007)
Exchange distance	-0.041	-0.042	-0.041			
	(0.031)	(0.031)	(0.031)			
Observations	3,305	3,319	3,305	4,443	4,461	4,443

Note: *All regressions include year and firm fixed effects. Robust standard errors clustered at the firm-level are presented in parentheses. , ** and * indicate significance at the 1%, 5% and 10% level, respectively. Regressions reflect changes ex ante firm characteristics between years 2007 and 2008.*

Placebo test

If the exclusion restriction holds, then our instruments should not affect firm outcomes other than through cloud adoption. One potential challenge is that fiber enablement and speeds may predict a broader upgrading of other types of ICT that subsequently impact firm performance. We test for this in Table 4, where we regress our instruments on a series of IT variables available to us in the e-commerce survey. These measures of IT are chosen as ones shown in the literature to impact firm performance, but which either do not rely on internet connectivity or were adopted by firms because of earlier intent technologies such as ADSL or ADSL2. These include percentage of employees using PCs, firm online sales activities and whether or not the firm is using advances production technologies (proxied by adoption of radio frequency identification, RFID) (Cordona et al 2013; Bloom et al 2014; DeStefano et al 2018).

We find that our instruments have poor first-stage predictive power for these other ICT measures, supporting the view that our instruments are valid. Regression 1 assesses the extent to which fiber enablement and distance predict within firm changes in the share of PCs per employee (See Table 4). The lack of predictive power of our instruments along with small F-statistics suggests that fiber rollout is not significantly linked to changes in the overall IT intensity of the firm. In regressions 2 and 3 we again find no statistically significant relationship between fiber broadband and changes in firm propensity to adopt e-commerce or the percentage of sales via e-commerce respectively. Similarly, our instruments do not predict the adoption of advanced production technologies, either RFID for product identification or RFID for monitoring and control of industrial production.

Table 4 Placebo test: Relationship between instruments and other digital technologies

	(1)	(2)	(3)	(4)	(5)
Dependent variable	**% Employees using PCs**	**Online sales**	**% Online sales in total sales**	**RFID identification**	**RFID production**
Specification					
Fibre	-1.334	0.001	0.314	-0.035	-0.035
	(0.762)	(0.013)	(0.341)	(0.027)	(0.033)
Fibre*distance	0.786	0.002	-0.086	0.024	0.020
	(0.452)	(0.008)	(0.205)	(0.014)	(0.014)
Observations	23243	23143	23143	3262	3262
Cragg-Donald F	5.42	0.14	0.91	4.47	2.80
Kleibergen-Paap F	1.71	0.06	0.56	1.60	1.09
J-stat (p-value)	0.58	0.75	0.27	0.40	0.63

Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age. Robust standard errors clustered at the firm-level are presented in parentheses. Regressions reflect years 2008, 2013 and 2015. Online sales is a binary variable reflecting positive e-commerce sales. RFID identification is a dummy variable reflecting use of RFID for product identification and RFID production reflects RFID for monitoring and control of industrial production. RFID information is only available for a subset of our sample, manufacturing firms.

Instrument Relevance

In Table 5 we provide evidence that fiber enablement and cable distances predict the adoption of cloud for our restricted sample of firms, even when including firm and year fixed effects. We report these regressions using a linear measure of distance (regressions 1 and 2) and a version in which we place firms into separate bins according to their cable distance (regression 3 and 4).[36] Regressions 1 and 3 include firm and year fixed effects, while in regressions 2 and 4 include additional firm control variables.

Across all four regressions we find that firms attached to fiber enabled telephone exchanges are significantly more likely to adopt cloud. We also find that this effect declines with the cable distance between the firm and the telephone exchange. In regressions 1 and 2 the cable distance variable is negative and suggests that for every kilometer increase in distance, the probability of adopting cloud drops by 3%.

In regressions 3 and 4 we express the distance variable differently, grouping firms according to their distance from the telephone exchange. These regressions use firms more than 2000

[36] We use the latter to test for any non-linearities within the data.

meters from the exchange as the baseline category, hence firms closer than this would be expected to be more likely to adopt cloud. The results in regressions 3 and 4 show that these effects are strongest for firms less than 500 meters from the exchange, followed by those between 500 and 1000 meters. This matches with the effects of cable distance on broadband speed from the telecoms engineering literature. Beyond this we find that distance from the telephone box has no additional predictive power and what matters is whether the exchange is fiber enabled or not. These results continue to hold when we add control variables (regressions 2 and 4). In terms of the control variables, we find that foreign owned and younger firms are more likely to use cloud computing.

Table 5: First stage: fiber enablement and distance on cloud adoption

Dependent variable: Cloud	**(1)**	**(2)**	**(3)**	**(4)**
Fiber Enablement	0.118***	0.119***	0.060***	0.062***
	(0.021)	(0.021)	(0.023)	(0.023)
Fiber*Distance	-0.030***	-0.030***		
	(0.008)	(0.008)		
Fiber, Dist. < 500 meters			0.060***	0.059***
			(0.020)	(0.020)
Fiber, Dist. 500-1000 meters			0.043**	0.044**
			(0.019)	(0.019)
Fiber, Dist. 1000-1500 meters			-0.021	-0.020
			(0.019)	(0.019)
Fiber, Dist. 1500-2000 meters			0.005	0.004
			(0.021)	(0.020)
Control variables:				
Multi-establishment		-0.001		-0.004
		(0.018)		(0.018)
Foreign owned		0.051**		0.053**
		(0.022)		(0.022)
Log age		-0.085***		-0.095***
		(0.016)		(0.015)
Observations	14,196	14,196	14,390	14,390

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Regressions reflect years 2008, 2013 and 2015.*

We explore the relationship between fiber access and cloud adoption further by separating firms cloud adoption into the seven different types available within the data (see Table A7 in the Appendix). That some types of cloud services are less dependent on the connection speeds offered by fiber broadband suggests the relevance of the instrument may differ between types of cloud service. For example, we would expect the bandwidth offered by connection speeds to be more important for tasks such as data processing and storage and less important for email access.

Across the table as a whole we continue to find that cloud adoption is positively related to enablement of the local telephone exchange and negatively with cable distance to the exchange, albeit to varying degrees of significance (See Table A7). The weakest effects of distance are found for office software, CRM software and running its own software (regressions 4, 6 and 7) and the strongest for databases, storage of files and finance and accounting software (regressions 1, 2 and 5).[37] [38]

We also investigate this further by using the classification system defined by Eurostat which clusters cloud services by their level of complexity (Eurostat, 2018).[39] According to this definition, basic cloud technologies include email, office software, or file storage via cloud (regression 8). A firm is identified as a user of medium cloud technologies, if they employ at

[37] The estimated coefficients are significant in all of these regressions, although the F-stats for their joint significance are weaker for CRM and own software.

[38] In this remainder of the paper, our treatment is cloud computing rather than a disaggregated measure of services. This approach follows the literature making similar assumptions that many of these technologies are complementary (Cordona et al., 2013 and Draca et al., 2006).

[39] See Gal et al. (2019) and Andrews et al. (2018), who use the same cloud measure.

least one of the basic cloud services along services for hosting the enterprise's databases (regression 9). Finally, a firm is flagged as a user of complex cloud technologies, if it uses at least one of the basic and mid cloud services as well as at least one advanced cloud services including, hosting the enterprise's database(s), Finance Software, CRM and processing services (regression 10).

As shown in Table A7, the instruments have the expected signs and are statistically significant for low-, medium- and high-tech versions of cloud services. The instruments are most relevant for medium- and high-tech versions (regressions 9 and 10), reflected in the F-statistics.

Main Results

Firm Scale and Establishment Organization

Before presenting the results from the instrumental variable estimations we begin by establishing that the use of cloud is positively correlated with measures of firm performance using OLS regressions (See Table A8).[40] We find cloud adoption is associated with greater employment, sales and labor productivity (regressions 1, 2 and 3) for all firms, with particularly strong correlations for young firms. [41]

In the baseline results of Table 7, we present instrumental variable estimates for the effects of cloud adoption on firm growth, measured by employment, sales and labor productivity, and

[40] We present results for the multi-establishments status of the firm, the number of establishments and births and deaths in Table A8 in the Appendix.

[41] Disaggregated forms of cloud and are also positive statistically related to firm performance except when we measure performance by employment and use finance and accounting software and CRM software cloud services. These lie just outside of significance at the 10% level. We choose not to report these regressions for brevity.

the distribution of activity across establishments, measured by the multi-establishment status and the number of establishment births and deaths. In all regressions we allow for separate effects for young and incumbent firms, where young are defined as being aged 5 years old or younger in 2008. We interact both our cloud variable and our fiber instruments with the young and incumbent dummies. The interaction terms are expressed such that they estimate the effect for young and incumbent firms separately, and therefore the estimated coefficient for each type is tested against the null of a zero effect.[42]

In the first stage regression we find that being attached to a fiber enabled exchange increases the probability of adopting cloud by 14% for incumbent firms, and by 42% for young firms. We also find that each kilometer from the exchange reduces the propensity to adopt cloud by just over 2.5% for incumbent firms and by 6.4% by for young firms. The first stage F-statistic of around 17 confirms the predictive power of the instruments. The test for overidentification is also comfortably passed, with the relevant p-value reported in the table.

In the second stage regressions we also find outcomes that are consistent with this idea of differences across young and incumbent firms. In regression 1 we find that cloud leads to significant increases in employment and sales for both young and incumbent firms.[43] These scale effects are much stronger for young firms. For employment, the paper finds that cloud adoption results in a coefficient of 1.087 for young firms and 0.735 for incumbents. As our data are measured for the years 2008, 2013 and 2015, this equates to approximately a 28%

[42] As a robustness test we also change the definition of a young firms to those aged 10 years old or less in 2008. The results are consistent to those in Table 7 and are available upon request.

[43] These results hold if we add a full set of industry-time dummies to the regression model.

annual increase in employment for young firms over this 7 year time period, compared to 15% for incumbent firms. [44] The results in column 3 suggest that the increase in sales and employment are approximately equal such that there is no significant effect of cloud on labor productivity.[45]

There is also evidence of an effect from cloud on firm fragmentation.[46] For younger firms who adopt cloud because of fiber, they are significantly less likely to become multi-establishment firms signified by a coefficient of -0.329. Conversely for incumbent firms we find no effect on the probability of becoming multi-establishment, but some evidence of experimentation and reorganization through an annual increase in the closure of establishments by roughly 12% over the sample period. [47] For both we find no significant effect on the creation of new establishments.

In order to ensure that our results are not somehow driven by young firms self-selecting into areas before the rollout, we rerun the results using data for 2006 as the baseline year, thereby ensuring that all firms in the sample were born during or before 2006. These results are reported in Table A12 in the Appendix. These results mirror those in Table 7 suggesting that the main results are not influenced by young firms self-selecting in areas where the rollout first occurred.

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[44] Following the evidence reported in Table A7 of a stronger effect of the instruments on the use of medium- and high-tech cloud and for data and for storage, in the Appendix Tables A9, A10 and A11 we report results using a measure of cloud for these groups only. The results are very similar to those in Table 7.

[45] We also assess whether there are differences between manufacturing versus service sector firms. We found no noticeable differences between firms in these two sectors, with results very similar to those in Table 7.

[46] These results are robust to the exclusion of the top 1% of young or incumbent firms based on their employment.

[47] Since the regression is log-linear, 12% is calculated as exp(0.626)-1/7, using the estimated coefficient from regression 5.

We have also rerun these results excluding firms that were born in 2007 and 2008, all of the main findings continue to hold. These results are available on request.[48] [49]

[48] In Table A13 we explore whether they are driven by small rather than young firms.

[49] We also find that the results are unchanged if we allow for heterogeneity associated with the volatility of sales within the industry. There is no evidence that the effects of cloud technology adoption differ across industries according to the volatility of sales.

Table 7: IV regressions: Impact of cloud on firm growth: young vs incumbents

Regression No.	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	**Log Employment**	**Log Sales**	**Labor productivity**	**Multi-plant**	**Log No. Establishment Deaths**	**Log No. Establishment Births**
Specification	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**
Cloud -incumbent	0.735**	0.606*	0.263	-0.030	0.626***	0.218
	(0.308)	(0.359)	(0.351)	(0.115)	(0.217)	(0.235)
Cloud-young	1.087***	1.034**	0.406	-0.329**	0.053	0.019
	(0.375)	(0.433)	(0.425)	(0.134)	(0.229)	(0.256)
First stage Cloud- Incumbent						
Fiber -incumbent	0.138***	0.134***	0.136***	0.136***	0.136***	0.136***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Fiber-young	-0.283***	-0.275***	-0.279***	-0.280***	-0.279***	-0.279***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
*Fiber*distance-incumbent*	-0.025***	-0.024***	-0.024***	-0.024***	-0.024***	-0.024***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
*Fiber*distance-young*	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
First stage Cloud-Young						
Fiber -incumbent	-0.023***	-0.021***	-0.022***	-0.022***	-0.022***	-0.022***
	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.005)
Fiber-young	0.415***	0.402***	0.408***	0.409***	0.407***	0.407***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
*Fiber*distance-incumbent*	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
*Fiber*distance-young*	-0.064***	-0.064***	-0.063***	-0.063***	-0.063***	-0.063***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Observations	14,246	14,331	14,381	14,440	14,440	14,440
Cragg-Donald F	17.47	17.20	17.16	17.27	17.25	17.25
Kleibergen-Paap F	9.88	9.69	9.70	9.76	9.74	9.74
J-stat(p-value)	0.78	0.37	0.73	0.36	0.68	0.94

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Birth and death are calculated as log (1 + no. deaths / births) over the period of the last 2 years. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Regressions reflect years 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.*

Geographic Organization

Cloud is likely to impact the how firms organize geographically. The reduced reliance on centralized IT departments and facilitating homogenous and flexible information access across the organization may enable greater geographic dispersion of activity within the firm. Conversely, advances in ICT have often gone hand-in-hand with increasing importance of face-to-face communication and the rise of tech clusters (Greenstein et al 2018).

We introduce different measures of the geographic dispersion of firm activity in Table 8. Our primary measure reflects the geographic dispersion of employees from the headquarters – a weighted average distance between establishments and their headquarters (weighted by the establishment share in firm employment). We decompose the weighted average distance variable into an unweighted average distance and a distance-employment covariance term. The unweighted average distance term captures how far establishments are located from the headquarters. The covariance term captures how employment is distributed across more proximate or more remote establishments. Finally, we add a measure of the number of local authorities (equivalent to counties in the US) in which the firm has establishments in. Equations detailing the geographic dispersion measures can be found in the Appendix.[50]

For young firms we find little impact of cloud adoption on geographic dispersion (see Table 8). These results are in line with what was found in Table 7 which indicated that cloud adoption led to employment and sales increases but not with becoming multi-establishment or adding/closing establishments. In comparison, for incumbent firms the effects of cloud on firm dispersion are pronounced. The weighted average distance shows how far the average

[50] In these regressions we include all firms. We report versions for incumbent firms in the Appendix in Table A14.

employee works (at their establishment) from the headquarters. Cloud adoption leads to the average employee working 25.34km farther from their headquarters. We decompose the weighted average distance into a covariance term and unweighted average distance. For incumbents we fail to find evidence that they are systematically more likely to close or open farther or more proximate establishments – as reflected in the unweighted distance. Instead, it is entirely that the distribution of employment shifts towards establishments more distant from the headquarters, reflected by a positive coefficient of 15.75 for the employment-distance covariance variable. Finally, for incumbent firms cloud adoption increases the number of different local authorities in which their establishments reside by roughly 4% annually. It therefore appears that cloud allows for the decentralization of information within the firm, thereby shifting employment away from the headquarters.

In order to understand if this simply reflected the movement of economic activity towards regions that were less costly, measured either in terms of the rental cost of commercial floor space or the wage rate of workers, we test for the types of local authorities that firms reorganize activity to. As reported in Table A15 in the Appendix, the effects of rental costs and wage rates exhibit no consistent pattern with how firms reorganize. For example, incumbent firms that use cloud technologies are more likely to move to regions that pay lower average wages or have cheaper rental costs for commercial floor space, however they are also more likely to move to regions that are more costly.

Overall, these results suggest very different mechanisms at work for younger and older firms. Cloud leads to a restructuring of incumbent organizations, closing more proximate establishments and decentralizing activity to local establishments away from the headquarters, even relocating workers within the firm. Whereas for younger firms we find no such geographic reorganization – which may reflect some start-ups with cloud-enabled business models increasingly needing face-to-face communication or an increased importance of social/employment/collaboration. Young firms that adopt cloud in their business models increase scale with no impact on geographical coverage.

Table 8: IV regressions: Impact of cloud on geographic dispersion

Regression No.	**(1)**	**(2)**	**(3)**	**(4)**
Dependent variable	**Avg distance (weighted)**	**Avg distance (unweighted)**	**Covariance**	**No. Local authorities**
Cloud -incumbent	25.343**	9.588	15.756*	0.255**
	(10.536)	(11.840)	(9.556)	(0.111)
Cloud-young	15.862	5.369	10.493	0.084
	(12.550)	(13.738)	(10.188)	(0.130)
First stage Cloud- Incumbent				
Fiber -incumbent	0.135***	0.135***	0.135***	0.136***
	(0.021)	(0.021)	(0.021)	(0.021)
Fiber-young	-0.279***	-0.279***	-0.279***	-0.279***
	(0.021)	(0.021)	(0.021)	(0.021)
*Fiber*distance-incumbent*	-0.024***	-0.024***	-0.024***	-0.024***
	(0.008)	(0.008)	(0.008)	(0.008)
*Fiber*distance-young*	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
First stage Cloud-Young				
Fiber -incumbent	-0.022***	-0.022***	-0.022***	-0.022***
	(0.005)	(0.005)	(0.005)	(0.005)
Fiber-young	0.410***	0.410***	0.410***	0.407***
	(0.033)	(0.033)	(0.033)	(0.033)
*Fiber*distance-incumbent*	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
*Fiber*distance-young*	-0.063***	-0.063***	-0.063***	-0.063***
	(0.019)	(0.019)	(0.019)	(0.019)
Observations	14,410	14,410	14,410	14,440
Cragg-Donald F	17.08	17.08	17.08	17.25
Kleibergen-Paap F	9.69	9.69	9.69	9.74
J-stat (p-value)	0.96	0.59	0.29	0.50

Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ****, ** and * indicate significance at the 1%, 5% and 10% level, respectively*. Weighted and unweighted average distance refers to the average distance of establishments from their headquarters, where the weights are the share of establishment employment in firm employment. The covariance term measures the correlation between establishment employment and distance from the headquarters, i.e. whether farther establishments are larger (a positive covariance), or closer establishments are larger (a negative covariance) in terms of employment. Number of local authorities reflects the log of the number of different local authorities in which the firm has establishments located. Regressions reflect years 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.

Employee mobility and cloud use

In the previous section we found that cloud leads to incumbent firms dispersing employment further from the headquarters. In this section we take the analysis down to the level of the employee, and examine where employees are being moved to, and in particular whether cloud computing is a key determinant of the mobility of workers across plants within the firm. Such movements may occur because of changes to the spatial organization of the production (Leamer and Storper, 2001; Duranton and Puga, 2005), because of the ability of management to share information and deal with problems (Bloom et al., 2014) or because of face-to-face interactions (Gaspar and Glaeser, 1998). This may lead to employees being shifted away from the headquarters to other plants. Alternatively, the technology may simply induce greater movement across any all of the plants the firm operates.

This analysis is at the employee-establishment-year level we can also assess the extent to which movement of workers is influenced by whether the HQ has cloud and/or whether the establishment has cloud. [51] The inclusion of establishment and worker fixed effects means we consider movement between existing establishments, neglecting opening and closure. [52]

[51] The first stages for each of the endogenous variables are reported in Tables A16 and A17 for completeness.

[52] Since the data on cloud adoption is at the level of the firm, we construct establishment cloud use based on the typical diffusion of cloud throughout firms (e.g. most firm subscriptions of cloud provide licensing to all establishments of the firm) and the technological prerequisites for adoption (access to high speed internet is essential). As such, establishment cloud use is set to one if the firm has adoption cloud and if the establishment has access to fiber broadband, and zero otherwise.

The results from columns 1 and 2 in Table 9 are consistent with those for the covariance term of employment and distance in Table 8, and confirm a reshuffling of employment within the firm. Workers in establishments using cloud technologies are significantly more likely to move compared to establishments that have not yet adopted the technology.[53] This holds when we include establishment fixed effects, but also worker fixed effects to control for unobservable time invariant characteristics of the individual. We find no evidence that this probability is affected by headquarters cloud use however.

In columns three and four we extend this to explore whether this reshuffling of employment is primarily associated with activity moving to or away from the headquarters. Irrespective of whether the HQ or its establishments adopt cloud we find no systematic movement of employees towards or away from the headquarters. In columns 5 and 6 we consider this in a different way and use a measure of the distance of the worker from the HQ. Again, we find no systematic evidence that these distances are affected by cloud adoption. These results therefore suggest that cloud adoption, in particular by establishments, is a determinant for employment mobility within the firm, but this reorganization of activity is across establishments rather than to and from the headquarters.

Table 9: Regression using matched employer-employee data

1 Period Ahead	**Probability of switching plants (within the firm)**		**Probability of switching to / from HQ**		**Change in Workplace Distance from HQ (of switchers within firm)**	
Second Stage IV estimates:	(1)	(2)	(3)	(4)	(5)	(6)
Establishment Cloud	0.100**	0.100**	0.060	0.060	-0.448	-0.443
	(0.047)	(0.046)	(0.039)	(0.039)	(0.309)	(0.308)
HQ Cloud	-0.036	-0.038	-0.045	-0.045	0.122	0.122
	(0.041)	(0.041)	(0.031)	(0.031)	(0.289)	(0.289)
Establishment Fixed Effects	Y	Y	Y	Y	Y	Y
Worker Fixed Effects		Y		Y		Y

[53] We present evidence for worker movement between t and t+1, similar results are obtained for 2 periods ahead.

Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	34108	34066	33370	33331	30339	30304
Cragg-Donald F	161.72	160.75	159.71	158.26	152.19	152.56
Kleibergen-Paap F	14.35	14.07	14.20	13.89	13.62	13.51
J-stat (p-value)	0.92	0.92	0.69	0.68	0.51	0.51

Notes: All regressions include controls for multi-establishment, ownership and firm age, as well as worker controls for age, tenure, tenure squared, skilled occupation dummy, sex and their interactions with sex. Robust standard errors clustered at the establishment-level are presented in parentheses. ***, ** *and * indicate significance at the 1%, 5% and 10% level, respectively* Instruments are fiber enablement and an interaction with log employment in 2008, and similarly at establishment level. Establishment (HQ) cloud reflects firm cloud adoption * establishment (HQ) fiber availability. Regressions reflect years 2008, 2013 and 2015. Probability of switching is measured one period ahead.

Conclusions

This paper presents new evidence on the mechanisms of cloud adoption and it impact on firm growth and geographic reorganization. We use novel instrumental variables on zip-code level availability and expected speeds (using local loop distances) of fiber broadband to predict firm cloud adoption. The instruments predict adoption in the types of digital services for which fiber broadband is a technical requirement (such as cloud data services) but not for those that are not (cloud email). Moreover, the instruments appear to be valid as the timing of fiber enablement and distance to the exchange are not correlated with ex-ante firm characteristics.

Consistent with much of the anecdotal evidence, there are differential impacts of cloud adoption for younger and incumbent firms. Younger firms that adopt cloud are more likely to increase employment and sales, but are less likely to have multiple establishments. For incumbent firms we find limited scale and no productivity impact, but instead they are more likely to reorganize activity, closing establishments and moving employment farther from the headquarters and across more local authorities. Cloud along with the fiber infrastructure therefore enables young firms to scale without increasing the geographic footprint while incumbents use the technology to reorganize, reduce their costs and geographically disperse. Moreover, the results find that cloud enhances worker mobility resulting in the movement of workers across establishments within a firm, although it has little effect on movements of individual workers between the headquarters and establishments.

Cloud appears to be distinct from earlier IT technologies that reinforced the scale advantages of incumbents (see for instance, Lashkari et al., 2019), and instead reduces a firm's fixed costs of IT, allowing startups to grow. Cloud adoption is linked to a decline in firm investments in IT capital and software, indicating that cloud enables for some substitution away from owning IT equipment. Cloud also decentralizes data, processing and software availability throughout the firm, going beyond earlier ICT that allowed information for specific tasks or workers, such as Enterprise Research Planning and CAD/CAM software (Bloom et al., 2014). Consistent with these earlier technologies, the dispersion of economic activity appears to follow the dispersion of information.

The results also indicate that policy makers may need to reconsider the types of policies that enable the use of these emerging technologies. One obvious area is for the provision and speed of fiber broadband. In fact, for most cloud services, fiber broadband is a pre-requisite. Many countries are actively working towards improving their broadband network. A survey carried out for the *OECD Digital Economy Outlook 2015* found that 27 of the 34 participating countries currently have a central national digital strategy, a key pillar of which involves expanding and enhancing broadband infrastructure (OECD 2015).

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FOR ONLINE PUBLICATION - APPENDIX

Types of cloud in E-commerce survey

Does this business buy any of the following cloud computing services used over the internet?

- *Email*: Email, as a cloud computing service
- *Software*: Office software for example word-processing or spreadsheets, as a cloud computing service
- *Databases*: Hosting the business' database(s) , as a cloud computing service
- *Storage of files*: Storage of files , as a cloud computing service
- *Finance Software*: Finance or accounting software applications, as a cloud computing service
- *CRM*: Customer relations management software, as a cloud computing service
- *Processing Own Software*: Computing capacity to the business' own software, as a cloud computing service

Weighted average distance of establishments from the headquarters

Intuition: distance of the mean employee from their headquarters.

It is a firm-level measure and is calculated $\overline{wdist_f}$:

$$\overline{wdist_f} = \sum_{p \in f} s_p \cdot dist_p$$

where $dist_p$ is the distance (in km) of establishments from their headquarters, and $s_p = \frac{emp_p}{emp_f}$ is the share of establishment employment in total firm employment.

Decomposition

Following Olley and Pakes (1996) we can decompose the weighted average as:

$$\overline{wdist_f} = \overline{dist_f} + Cov(dist_p, emp_p)$$

Unweighted average distance of establishments from the headquarters

Intuition: distance of the mean establishment from their headquarters.

It is a firm-level measure and is calculated $\overline{dist_f}$:

$$\overline{dist}_f = \sum_{p \in f} \frac{1}{N_f} \cdot dist_p$$

where $dist_p$ is the distance (in km) of establishments from their headquarters, and N_f is the number of establishments of the firm.

Covariance between establishment employment and establishment distance from the headquarters

Intuition: measures how employment is distributed across establishments by their proximity - are farther establishments larger (+ve covariance) or closer establishments larger (-ve covariance).

$$Cov(dist_p, emp_p) = \sum_{p \in f} (s_p - \bar{s}_f) \cdot (dist_p - \overline{dist}_f)$$

where $\bar{s}_f$ is the unweighted mean share of establishment employment. Other terms are defined as above.

Table A1 Summary Statistics of Cloud Adoption

	2013		2015	
Variable	**mean**	**st.dev.**	**mean**	**st.dev.**
***All firms* (14,390 obs.)**				
Cloud	0.407	0.491	0.466	0.499
Cloud Databases	0.173	0.378	0.198	0.399
Cloud Storage of files	0.242	0.429	0.310	0.463
Cloud Email	0.192	0.394	0.273	0.446
Cloud Office Software	0.103	0.305	0.205	0.404
Cloud Finance Software	0.089	0.280	0.107	0.309
Cloud CRM	0.125	0.331	0.141	0.348
Cloud Processing Own Software	0.099	0.299	0.121	0.326
***Young firms* (1,872 obs.)**				
Cloud	0.352	0.478	0.353	0.478
Cloud Databases	0.183	0.387	0.167	0.373
Cloud Storage of files	0.219	0.414	0.239	0.427
Cloud Email	0.206	0.405	0.237	0.423
Cloud Office Software	0.112	0.316	0.175	0.381
Cloud Finance Software	0.089	0.284	0.119	0.324
Cloud CRM	0.120	0.326	0.116	0.320
Cloud Processing Own Software	0.123	0.329	0.096	0.300
***Incumbent firms* (12,518 obs.)**				
Cloud	0.414	0.493	0.484	0.500
Cloud Databases	0.172	0.377	0.203	0.402
Cloud Storage of files	0.245	0.430	0.321	0.467
Cloud Email	0.191	0.393	0.279	0.448
Cloud Office Software	0.102	0.303	0.210	0.407
Cloud Finance Software	0.085	0.279	0.105	0.307
Cloud CRM	0.125	0.331	0.145	0.352
Cloud Processing Own Software	0.097	0.300	0.124	0.330

Notes. These present statistics from a balanced panel of observations for comparison of adoption across time for the same set of firms – a subset of our estimation sample of firms.

Table A2: Summary statistics of other variables

	All firms (14,390 obs.)		Young firms (1,916 obs.)		Incumbent firms (12,422 obs.)	
Variable	**mean**	**Sd**	**mean**	**Sd**	**mean**	**Sd**
(Log) Employment	4.45	2.29	2.70	1.92	4.72	2.23
(Log) Sales	9.08	2.61	6.96	2.13	9.41	2.52
(Log) Labor Productivity	4.58	1.23	3.97	1.54	4.67	1.15
Multi-establishment dummy	0.54	0.50	0.33	0.47	0.52	0.50
Number of establishment deaths	3.92	68.82	3.43	18.39	39.82	298.80
Number of establishment births	4.03	51.07	0.25	1.71	4.47	73.77
Weighted average distance establishments headquarter (km)	37.53	70.45	12.09	44.44	41.39	72.36
Unweighted average distance establishments headquarter (km)	50.08	81.49	16.82	53.09	55.12	83.81
Covariance establishment distance-establishment employment	-12.54	36.65	-4.73	26.61	-13.73	37.79
Fiber enabled	0.52	0.50	0.51	0.50	0.52	0.50
Exchange distance	1.27	0.81	1.27	0.85	1.27	0.81
Number of local authorities	12.95	44.41	2.35	9.47	14.55	47.26
Foreign owned	0.19	0.39	0.07	0.26	0.20	0.40
Log age	3.02	0.70	1.72	0.69	3.22	0.45

A3: Summary statistics of workers-level regressions

Variable	mean	Sd	n
1 period Probability of switching establishments (within the firm)	0.04	0.19	34,108
1 period Probability of switching to / from hq	0.02	0.14	33,484
1 period Change in (Log km) Workplace Distance from HQ (of switchers within firm)	0.08	1.30	30,467
HQ cloud	0.30	0.46	34,108
Establishment cloud	0.29	0.45	34,108
HQ Fiber	0.44	0.50	34,108
*Establishment Fiber*HQ Fiber*	0.42	0.49	34,108
Multi-establishment	0.81	0.40	34,108
Foreign	0.38	0.48	34,108
Firm Age	28.73	9.63	34,108
Exchange Distance	1.27	0.82	34,108
Worker Age	40.01	11.77	34,108
Tenure	7.51	8.30	34,108
Skilled Worker (Soc 2010 classification)	0.45	0.50	34,108
Female	0.30	0.46	34,108

A4: Correlation of different cloud types

	Cloud databases	*Cloud storage of files*	*Cloud email*	*Cloud office software*	*Cloud finance software*	*Cloud CRM*	*Cloud own software*
Cloud databases	1						
Cloud storage of files	0.548	1					
Cloud email	0.432	0.541	1				
Cloud office software	0.402	0.519	0.621	1			
Cloud finance software	0.429	0.331	0.314	0.335	1		
Cloud CRM	0.440	0.376	0.334	0.337	0.362	1	
Cloud processing own software	0.464	0.395	0.322	0.355	0.354	0.387	1

A5: OLS Correlations, complementarities between cloud and IT intensity

Dependent variable:	**(1)**	**(2)**	**(3)**	**(4)**
Outcome	**Log IT investment per employee**	**Share of computer services expenditures in total costs**	**Log IT investment per employee**	**Share of computer services expenditures in total costs**
Cloud	-0.672***	-0.001		
	(0.056)	(0.001)		
Cloud - incumbent			-0.702***	-0.001
			(0.060)	(0.001)
Cloud - young			-0.442***	-0.000
			(0.129)	(0.003)
Observations	14,390	14,390	14,390	14,390

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.*

A6: OLS Correlations between types of cloud services and computer services expenditures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable:	**Share of computer services expenditures in total costs**						
Type of cloud	Cloud databases	Cloud storage of files	Cloud email	Cloud office software	Cloud finance software	Cloud CRM	Cloud processing own software
Cloud	-0.002*	-0.001	-0.001	-0.001	0.001	-0.003**	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	14,390	14,390	14,390	14,390	14,390	14,390	14,390

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively All regressions reflect the time periods 2008, 2013 and 2015.*

A7: Instrument relevance for different types of cloud services

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable	**Cloud databases**	**Cloud storage of files**	**Cloud email**	**Cloud office software**	**Cloud finance software**	**Cloud CRM**	**Cloud own software**	**Cloud Low-Tech**	**Cloud Med-Tech**	**Cloud High-Tech**
Specification	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**	**IV**
Fiber	0.080***	0.090***	0.062***	0.048***	0.061***	0.042***	0.048***	0.029**	0.080***	0.092***
	(0.016)	(0.019)	(0.017)	(0.014)	(0.013)	(0.014)	(0.013)	(0.015)	(0.016)	(0.018)
Fiber*distance	-0.026***	-0.022***	-0.017***	-0.008	-0.011**	-0.010*	-0.010**	-0.003	-0.026***	-0.021***
	(0.006)	(0.007)	(0.007)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)
Observations	14,196	14,196	14,196	14,196	14,196	14,196	14,196	14,196	14,196	14,196
K-P F-stat	25.51	20.57	11.61	8.13	18.57	7.64	10.79	2.11	15.11	14.30

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. K-P F stat refers to the Kleibergen-Paap F statistic. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Regressions reflect years 2008, 2013 and 2015.*

A8: OLS regressions: correlations between cloud adoption and firm performance

Regression No.	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Dependent variable:	**Log Employment**	**Log Sales**	**Labor productivity**	**Multi-plant**	**Log No. Establishment Deaths**	**Log No. Establishment Births**
Cloud -incumbent	0.047***	0.112***	0.133***	0.012	0.095***	-0.055***
	(0.017)	(0.021)	(0.021)	(0.008)	(0.018)	(0.020)
Cloud-young	0.393***	0.515***	0.306***	-0.111***	-0.035	-0.034
	(0.082)	(0.099)	(0.100)	(0.028)	(0.029)	(0.035)
Observations	14,196	14,331	14,331	14,390	14,390	14,390

*Note: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Regressions reflect years 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.*

A9: IV regressions: Impact of cloud on firm growth: young vs incumbents. Cloud Medium tech

	(1)	(2)	(3)	(4)	(6)	(7)
Dependent variable	Log Employment	Log Sales	Log Sales per worker	Multi plant	Log No. Establishment Deaths	Log No. Establishment Births
Specification	IV	IV	IV	IV	IV	IV
Cloud-incumbent	1.062**	0.683	0.344	-0.068	0.994***	0.306
	(0.430)	(0.500)	(0.489)	(0.166)	(0.345)	(0.357)
Cloud-young	1.715***	1.537**	0.685	-0.699***	-0.197	-0.131
	(0.627)	(0.679)	(0.658)	(0.224)	(0.367)	(0.398)
First stage Cloud- Incumbent						
Fiber -incumbent	0.088***	0.085***	0.085***	0.087***	0.087***	0.087***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Fiber-young	-0.121***	-0.119***	-0.119***	-0.121***	-0.121***	-0.121***
	(0.017)	(0.017)	(0.017)	(0.016)	(0.016)	(0.016)
Fiber*distance-incumbent	-0.024***	-0.023***	-0.023***	-0.023***	-0.023***	-0.023***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Fiber*distance-young	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
First stage Cloud-Young						
Fiber -incumbent	-0.009**	-0.009**	-0.009**	-0.009**	-0.009**	-0.009**
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Fiber-young	0.201***	0.200***	0.200***	0.200***	0.200***	0.200***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Fiber*distance-incumbent	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fiber*distance-young	-0.035**	-0.037**	-0.037**	-0.037**	-0.037**	-0.037**
	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Observations	14196	14331	14331	14390	14390	14390
Cragg-Donald F	13.16	12.59	12.59	12.99	13.05	13.05
Kleibergen-Paap F	7.76	7.41	7.41	7.63	7.68	7.68
J-stat(p-value)	0.49	0.19	0.63	0.40	0.94	0.90

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008. A firm is identified as a user of medium cloud technologies, if they employ at least one of the basic cloud services along with the service for hosting the enterprise's database(s) (Eurostat, 2018).*

A10: IV regressions: Impact of cloud on firm growth: young vs incumbents. Cloud High Tech

	(1)	(2)	(3)	(4)	(6)	(7)
Dependent variable	Log Employment	Log Sales	Log Sales per worker	Multi plant	Log No. Establishment Deaths	Log No. Establishment Births
Specification	IV	IV	IV	IV	IV	IV
Cloud-incumbent	1.090***	0.796*	0.378	-0.024	0.908***	0.323
	(0.420)	(0.475)	(0.463)	(0.155)	(0.341)	(0.343)
Cloud-young	1.536***	1.433**	0.624	-0.556***	-0.195	-0.080
	(0.527)	(0.569)	(0.561)	(0.184)	(0.324)	(0.343)
First stage Cloud- Incumbent						
Fiber -incumbent	0.098***	0.094***	0.094***	0.096***	0.096***	0.096***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Fiber-young	-0.115***	-0.114***	-0.114***	-0.115***	-0.115***	-0.115***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Fiber*distance-incumbent	-0.018**	-0.017**	-0.017**	-0.017**	-0.017**	-0.017**
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Fiber*distance-young	-0.001	-0.001	-0.001	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
First stage Cloud-Young						
Fiber -incumbent	-0.010***	-0.010***	-0.010***	-0.010***	-0.010***	-0.010***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Fiber-young	0.238***	0.235***	0.235***	0.235***	0.235***	0.235***
	(0.028)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Fiber*distance-incumbent	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fiber*distance-young	-0.041**	-0.042***	-0.042***	-0.042***	-0.042***	-0.042***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Observations	14196	14331	14331	14390	14390	14390
Cragg-Donald F	12.61	12.10	12.10	12.61	12.64	12.64
Kleibergen-Paap F	7.78	7.48	7.48	7.78	7.80	7.80
J-stat(p-value)	0.90	0.40	0.67	0.32	0.65	0.90

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008. A firm is identified as a user of complex cloud technologies, if it uses at least one of the basic cloud services as well as at least one of the more advanced cloud services including, hosting the enterprise's database(s), Finance Software, CRM and processing services (Eurostat, 2018).*

A11: IV regressions: Impact of cloud on firm growth: young vs incumbents. Cloud data and storage

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Log Sales	Log Sales per worker	Multi plant	Log No. Establishment Deaths	Log No. Establishment Births
Specification	IV	IV	IV	IV	IV	IV
Cloud-incumbent	0.821**	0.644	0.337	-0.026	0.731***	0.242
	(0.354)	(0.414)	(0.400)	(0.129)	(0.247)	(0.261)
Cloud-young	1.265***	1.202**	0.562	-0.424***	0.003	-0.026
	(0.459)	(0.516)	(0.506)	(0.157)	(0.261)	(0.290)
First stage Cloud- Incumbent						
Fiber -incumbent	0.119***	0.115***	0.115***	0.118***	0.118***	0.118***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Fiber-young	-0.203***	-0.201***	-0.201***	-0.200***	-0.200***	-0.200***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Fiber*distance-incumbent	-0.024***	-0.023***	-0.023***	-0.023***	-0.023***	-0.023***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Fiber*distance-young	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
First stage Cloud-Young						
Fiber -incumbent	-0.017***	-0.016***	-0.016***	-0.016***	-0.016***	-0.016***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Fiber-young	0.317***	0.313***	0.313***	0.314***	0.313***	0.313***
	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)	(0.031)
Fiber*distance-incumbent	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fiber*distance-young	-0.058***	-0.057***	-0.057***	-0.057***	-0.057***	-0.057***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.017)	(0.017)
Observations	14,196	14,331	14,331	14,390	14,390	14,390
Cragg-Donald F	15.78	15.16	15.16	15.63	15.60	15.60
Kleibergen-Paap F	9.14	8.78	8.78	9.06	9.02	9.02
J-stat(p-value)	0.31	0.33	0.67	0.35	0.79	0.94

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.*

A12: IV regressions: Impact of cloud on firm growth: young vs incumbents: 2006 as baseline

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Log Sales	Log Sales per worker	Multi plant	Log No. Establishment Deaths	Log No. Establishment Births
Specification	IV		IV	IV	IV	IV
Cloud-incumbent	1.023***	0.434	-0.132	0.260**	0.661***	0.124
	(0.341)	(0.395)	(0.410)	(0.130)	(0.199)	(0.240)
Cloud-young	1.527***	0.919**	0.125	-0.157	0.395*	0.048
	(0.406)	(0.465)	(0.489)	(0.157)	(0.216)	(0.260)
First stage Cloud- Incumbent						
Fiber -incumbent	0.138***	0.135***	0.135***	0.137***	0.135***	0.135***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Fiber-young	-0.293***	-0.291***	-0.291***	-0.292***	-0.288***	-0.288***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Fiber*distance-incumbent	-0.023***	-0.021**	-0.021**	-0.021**	-0.021**	-0.021**
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Fiber*distance-young	-0.003	-0.002	-0.002	-0.002	-0.002	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
First stage Cloud-Young						
Fiber -incumbent	-0.022***	-0.022***	-0.022***	-0.023***	-0.023***	-0.023***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)
Fiber-young	0.428***	0.422***	0.422***	0.421***	0.421***	0.421***
	(0.034)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
Fiber*distance-incumbent	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fiber*distance-young	-0.078***	-0.077***	-0.077***	-0.078***	-0.078***	-0.078***
	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Observations	13,069	13,208	13,208	13,285	13,285	13,285
Cragg-Donald F	19.00	18.67	18.67	19.08	18.85	18.85
Kleibergen-Paap F	10.38	10.31	10.31	10.47	10.42	10.42
J-stat (p-value)	0.86	0.57	0.54	0.04	0.43	0.28

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008*

A13: IV regressions: Impact of cloud on firm growth: incumbents, small and large young firms

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Log Sales	Labor productivity	Multi plant	Log No. Establishment Deaths	Log No. Establishment Births
Specification	IV			IV	IV	IV
Cloud - incumbent	0.809***	0.611*	0.282	-0.033	0.607***	0.148
	(0.313)	(0.355)	(0.350)	(0.119)	(0.217)	(0.226)
Cloud-young-small	1.329***	1.107**	0.404	-0.357**	0.066	0.017
	(0.401)	(0.447)	(0.445)	(0.147)	(0.238)	(0.256)
Cloud-young-large	-0.723**	0.447	1.206***	-0.107	-0.026	-0.915***
	(0.322)	(0.381)	(0.434)	(0.130)	(0.233)	(0.343)
Observations	13,996	14,131	14,131	14,190	14,190	14,190
Cragg-Donald F	11.38	11.16	11.16	11.24	11.22	11.22
Kleibergen-Paap F	6.69	6.56	6.56	6.61	6.59	6.59
J-stat(p-value)	0.85	0.50	0.84	0.40	0.70	0.95

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008.*

A14: IV regressions: Impact of cloud on geographic dispersion – incumbents only

	(1)	(2)	(3)	(4)
Dependent variable	Average distance (weighted)	Average distance	Covariance	No. Local authorities
Cloud -incumbent	26.528*	12.939	13.589	0.179
	(15.934)	(17.322)	(13.947)	(0.150)
First stage Cloud- Incumbent				
Fiber -incumbent	0.101***	0.101***	0.101***	0.101***
	(0.023)	(0.023)	(0.023)	(0.023)
Fiber*distance-incumbent	-0.023***	-0.023***	-0.023***	-0.023***
	(0.009)	(0.009)	(0.009)	(0.009)
Observations	11,467	11,467	11,467	11,488
Cragg-Donald F	17.58	17.58	17.58	17.74
Kleibergen-Paap F	9.97	9.97	9.97	10.06
J-stat (p-value)	0.99	0.42	0.27	0.88

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Average distance refers to the weighted average distance of establishments from their headquarters, where the weights are the share of establishment employment in firm employment. The covariance term measures the correlation between establishment employment and distance from the headquarters, i.e. whether farther establishments are larger (a positive covariance), or closer establishments are larger (a negative covariance) in terms of employment. All regressions reflect the time periods 2008, 2013 and 2015. Incumbent are defined as firms being older than 5 years old in 2008.*

A15: IV regressions: Dispersion to Low / High Cost Local Authorities

Regression No.	**(1)**	**(2)**	**(3)**	**(4)**
Dependent variable	**No. Local authorities Below Median Rateable Value**	**No. Local authorities Above Median Rateable Value**	**No. Local authorities Below Median Wage**	**No. Local authorities Above Median Wage**
Cloud -incumbent	0.160*	0.304***	0.225**	0.258***
	(0.088)	(0.103)	(0.095)	(0.097)
Cloud-young	0.019	0.178	0.098	0.102
	(0.095)	(0.121)	(0.106)	(0.114)
First stage Cloud-Incumbent				
Fiber -incumbent	0.134***	0.134***	0.134***	0.134***
	(0.021)	(0.021)	(0.021)	(0.021)
Fiber-young	-0.275***	-0.275***	-0.275***	-0.275***
	(0.021)	(0.021)	(0.021)	(0.021)
*Fiber*distance-incumbent*	-0.024***	-0.024***	-0.024***	-0.024***
	(0.008)	(0.008)	(0.008)	(0.008)
*Fiber*distance-young*	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
First stage Cloud-Young				
Fiber -incumbent	-0.020***	-0.020***	-0.020***	-0.020***
	(0.005)	(0.005)	(0.005)	(0.005)
Fiber-young	0.401***	0.401***	0.401***	0.401***
	(0.033)	(0.033)	(0.033)	(0.033)
*Fiber*distance-incumbent*	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
*Fiber*distance-young*	-0.063***	-0.063***	-0.063***	-0.063***
	(0.019)	(0.019)	(0.019)	(0.019)
Observations	14,390	14,390	14,390	14,390
Cragg-Donald F	17.29	17.29	17.29	17.29
Kleibergen-Paap F	9.73	9.73	9.73	9.73
J-stat (p-value)	0.68	0.44	0.67	0.31

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015. Young are defined as being aged 5 years old or younger in 2008 and incumbent are defined as being older than 5 years old in 2008. The median local authority in terms of rateable value (a measure of commercial property values) and wages are fixed in 2008.*

A16: First stage for cloud-worker results – endogenous variable: Establishment Cloud

1 Period Ahead	**Probability of switching plants (within the firm)**		**Probability of switching to / from hq**		**Change in Workplace Distance from HQ**	
First Stage IV estimates: Establishment Cloud	(1)	(2)	(3)	(4)	(5)	(6)
HQ Fiber	-0.117**	-0.115**	-0.116**	-0.114**	-0.120**	-0.117**
	(0.053)	(0.053)	(0.054)	(0.054)	(0.054)	(0.055)
HQ Fiber * Initial Firm Size	0.044	0.043	0.044	0.044	0.047	0.047
	(0.039)	(0.039)	(0.040)	(0.040)	(0.039)	(0.039)
Establishment Fiber * HQ Fiber	0.245***	0.245***	0.243***	0.244***	0.248***	0.249***
	(0.045)	(0.045)	(0.046)	(0.046)	(0.046)	(0.046)
Establishment Fiber * HQ Fiber * Initial Firm Size	0.023	0.023	0.023	0.023	0.022	0.022
	(0.039)	(0.039)	(0.040)	(0.040)	(0.039)	(0.039)
Establishment Fixed Effects	Y	Y	Y	Y	Y	Y
Worker Fixed Effects		Y		Y		Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	34,108	34,066	33,370	33,331	30,339	30,304

*Notes: All regressions include controls for multi-establishment, ownership and firm age, as well as worker controls for age, tenure, tenure squared, skilled occupation dummy, sex and their interactions with sex. Robust standard errors clustered at the establishment-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015.*

A17: First stage for cloud-worker results– endogenous variable: HQ Cloud

1 Period Ahead	**Probability of switching plants (within the firm)**		**Probability of switching to / from HQ**		**Change in Workplace Distance from HQ**	
First Stage IV estimates: HQ Cloud	(1)	(2)	(3)	(4)	(5)	(6)
HQ Fiber	0.042	0.043	0.042	0.044	0.040	0.042
	(0.042)	(0.042)	(0.043)	(0.043)	(0.044)	(0.044)
HQ Fiber * Initial Firm Size	0.080**	0.079**	0.085**	0.084**	0.080**	0.079**
	(0.036)	(0.036)	(0.037)	(0.037)	(0.038)	(0.038)
Establishment Fiber * HQ Fiber	-0.047	-0.047	-0.050	-0.050	-0.049	-0.049
	(0.037)	(0.037)	(0.038)	(0.038)	(0.039)	(0.039)
Establishment Fiber * HQ Fiber * Initial Firm Size	-0.013	-0.012	-0.018	-0.017	-0.011	-0.010
	(0.036)	(0.036)	(0.037)	(0.037)	(0.037)	(0.037)
Establishment Fixed Effects	Y	Y	Y	Y	Y	Y
Worker Fixed Effects		Y		Y		Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	34108	34066	33370	33331	30339	30304

Notes: All regressions include controls for multi-plant, ownership and firm age, as well as worker controls for age, tenure, tenure squared, skilled occupation dummy, sex and their interactions with sex. Robust standard errors clustered at the plant-level are presented in parentheses. All regressions reflect the time periods 2008, 2013 and 2015

A18: IV regressions: Impact of cloud on IT investment and costs

	(1)	(2)
Dependent variable	**Log IT investment per employee**	**Share of computer services expenditures it total costs**
Specification	**IV**	**IV**
Cloud-incumbent	-1.432*	-0.001
	(0.750)	(0.008)
Cloud-young	-0.816	0.009
	(0.855)	(0.010)
First stage Cloud- Incumbent		
Fiber -incumbent	0.134***	0.134***
	(0.021)	(0.021)
Fiber-young	-0.275***	-0.275***
	(0.021)	(0.021)
Fiber*distance-incumbent	-0.024***	-0.024***
	(0.008)	(0.008)
Fiber*distance-young	-0.001	-0.001
	(0.002)	(0.002)
First stage Cloud-Young		
Fiber -incumbent	-0.020***	-0.020***
	(0.005)	(0.005)
Fiber-young	0.401***	0.401***
	(0.033)	(0.033)
Fiber*distance-incumbent	-0.000	-0.000
	(0.000)	(0.000)
Fiber*distance-young	-0.063***	-0.063***
	(0.019)	(0.019)
Observations	14,390	14,390
Cragg-Donald F	17.29	17.29
Kleibergen-Paap F	9.73	9.73
J-stat (p-value)	0.90	0.00

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-establishment dummy, foreign owned dummy and log age, which are not reported for brevity. Robust standard errors clustered at the firm-level are presented in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. All regressions reflect the time periods 2008, 2013 and 2015.*

Data References

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