CLOUD COMPUTING AND FIRM GROWTH[1]

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The arrival of the cloud has enabled a shift in the nature of ICT use, from investment in sunk capital to a pay-on-demand service that allows firms to rapidly scale up. This paper uses new firm-level data to examine the impact of cloud on firm growth in the UK, using zipcode-level instruments of the timing of high-speed fibre availability and expected speeds. We find cloud leads to the growth of young firms in terms of employment and productivity, but they become more concentrated in fewer plants. For older firms we find no scale or productivity growth, but instead disperse activity by closing plants and moving employment further from the headquarters. In addition, the plants that close tend to be those without access to fibre broadband.

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[1] Comments are very welcome on this draft. We would like to thank Giuseppe Berlingieri, Erik Brynjolfsson, Oliver Falck, Nick Johnstone, Carlo Menon, Frank Nagle, Giuseppe Nicoletti, Stephen P. Ryan and participants at CESIfo Economics of Digitization Conference for very helpful comments and suggestions.

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I. INTRODUCTION

Over the past decade, there has been a fundamental shift in the way most firms purchase information and communication technologies (ICT), towards what is known as the cloud (Van Ark, 2016; OECD, 2015). Firms are able to purchase data storage, processing and software as a service through the cloud using a 'pay on demand' function. Whilst first launched by Amazon Web Services in 2006,[2] from 2010, the number of cloud providers increased (such as Google, IBM, Microsoft, and Oracle) and the price of such services fell (Barr, 2009), allowing firms to customise their ICT needs with an increasingly varied diet of software and hardware services (McKendrick, 2011). Crucially for our paper, over the same time period, the diffusion of high-speed internet in several countries rapidly enabled more firms to access these cloud services, to over 50% in our UK data in 2015. Recent estimates suggest that expenditures on cloud services have been growing at a rate 4.5 times faster than traditional IT investment expenditure since 2009, such that by 2016 cloud represented 37.2% of global IT infrastructure investment (Forbes, 2017; IDC, 2017).

Outside of the economics literature, it has been claimed that cloud is a disruptive technology that impacts firm growth and organisation across different dimensions (Economist, 2018). Firstly, firms no longer need to own their IT infrastructure, nor employ specialist IT workers to install and maintain them, often at the headquarters. Instead, data and processing infrastructure can be decentralised to workers throughout the firm – and available remotely via the cloud (OECD, 2015; OECD, 2014). This may result in restructuring of incumbent firms by downscaling centralised IT departments, or more generally, dispersing information and activity away from the headquarters (Economist, 2018). Secondly, the shift from a sunk IT investment to a largely variable cost, may enable new business models and firm types. New entrants may employ flexible business models to scale their operations quickly without the need for acquiring a mass of ICT assets or labour - thereby obtaining 'scale without mass'

[2] Amazon Web Services launched Elastic Computing Cloud.

and labour productivity gains.[3] We explicitly consider firm growth across these various scale, productivity and geographic dimensions.

In this paper, we provide the first econometric analysis of the effects of cloud computing on firm organisation and growth. To do so we 1) use newly available data on the adoption of cloud services for UK firms; 2) given the disruptive nature of the technology, examine firm impacts across a range of different scale, productivity and geographic dimensions; 3) allow for inherent differences in the likely effects of cloud across young and incumbent firms; and 4) take seriously endogeneity concerns over the adoption of the cloud and use an instrumental variable approach.[4]

For new firms, the dominant effect of this change in the costs of ICT from a fixed to a variable cost is expected to be on the type of business models adopted. The sunk investments associated with ICT can be particularly burdensome for new entrants, given their financial constraints due to their lack of credit history, demand uncertainty and the intangible nature of their 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 are the opportunities cloud offers for incumbent firms, those who have invested in organisational models based on previous ways of purchasing and using ICT. There is a suggestion from within the IT industry that the cost benefits for incumbents are less clear, due to the problem of legacy software, which often represent important intangible assets for such firms. Cloud may enable cost savings and restructuring by reducing their reliance on internal IT capital and IT specialists, but at the disadvantage that the firm-specific knowledge of this IT, and in particular their software, is lost. This can cause significant problems and delays when fixing problems due for example to service failures.

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[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.

[4] 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 difficulties in the measurement of a new technology, such as limited data on the use of cloud and the types of services purchased (Bryne et al, 2017; Brynjolfsson et al, 2017).

There are also possible effects on the geographic organisation of incumbent firms. The lower cost of accessing information at a distance, would typically be thought to facilitate greater geographic dispersion of firm activity away from the headquarters (Bloom et al., 2014). However, working in the opposite direction are the effects of 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. This monitoring and problem solving is more likely to be done by senior managers and therefore to occur at the centre of the firm. Which of these effects dominates for cloud is unclear.

This paper also contributes to our understanding of ICT more generally by including both traditional and relatively unexplored dimensions of how firms grow. These metrics include employment and labour productivity, but also measures of their spatial fragmentation, which we measure using the number of plants, plant births and deaths. Alongside these we introduce two new measures of geographic concentration.[5] First, we measure the unweighted and weighted average distance between plants and the firm headquarters (weighted by the share of plant employment in firm employment). Secondly, we construct a distance-employment covariance term to measure how employment is distributed across more proximate or more remote plants. This term reflects whether distant plants are larger in terms of employment (a positive covariance between distance and plant size), or closer plants are larger (a negative covariance).

These are questions for which endogeneity concerns surrounding the adoption of cloud technologies feature heavily. To address such concerns, this paper uses novel zipcode-level data on the availability and expected speeds of high-speed fibre 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).[6] The growth of cloud services is a phenomenon that has gone hand-in-hand with the diffusion

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[5] These metrics are adapted from extensive use productivity literature, which measures the distribution of employment activity across firms of different productivity (Criscuolo et al. 2014). Instead, we use these to measure the geographic distribution of employment activity across different plants within a firm.

[6] While this is the case for most cloud services, an exception is email services which can be accessed with ADSL broadband.

of high-speed fibre broadband. We are only aware of one other paper using the availability of fibre as an instrumental variable. [7]

These instruments have the expected relationship with cloud adoption and are strongly correlated with this decisions. We find that firms with access to fibre along with those with shorter cable (local loop) distances to the nearest telephone exchange enabling faster fibre speeds are more likely to adopt cloud than those connected to exchanges not yet enabled with fibre or those with fibre access but longer cable distances. Importantly we find that these cable distance instruments behave in a manner that is closely aligned with the predictions from the telecoms engineering literature. In particular, our fibre instruments only have the strongest predictive power over short local loop distances (within 1000 metres) where fibre offers a substantial speed improvement over prior ADSL broadband technology.

To preview the main results of the paper we find substantial heterogeneity for the effects of cloud when distinguishing between young and incumbent firms. Our key findings are as follows. Firstly, younger firms that adopt cloud are more likely to grow in employment and labour productivity (for certain young firms), but are less likely to have multiple plants. Secondly, for incumbent firms that adopt cloud, we find no scale or productivity effects, but instead they are more likely to reorganise, closing plants and decentralising activities (employment) further from the headquarters and in more local authorities. Thirdly, firms who adopt the cloud are *only* more likely to close plants without fibre availability, but for plants with fibre access there is no effect on plant closure. Fourthly, these highlight the advantage of examining effects across various firm dimensions, for example, since younger firms account for a smaller share of overall economic activity, it is unsurprising that sector-level studies have found these productivity impacts hard to measure to-date (as noted by Bryne et al. 2018). Taken together cloud appears to have important implications for how young firms grow, and how incumbent firms reorganise to take advantage of emerging technologies.

[7] Fabling and Grimes (2016) examine how the diffusion of fibre impact the employment and productivity of New Zealand firms, and use the proximity to nearby schools as an instrument (which were the target of the fibre rollout programme).

We use a difference-in-difference strategy combined with two zipcode-level instruments based on the pre-existing telephone exchange network in the UK. Firstly, the availability of fibre broadband and secondly, expected fibre speeds.[8] The adoption of cloud is unlikely to be randomly determined, instead firms choose to adopt cloud given the expected benefits. The large flows of data generated by cloud use mean that access to fibre and its expected speed is a prerequisite for cloud adoption. Prior technologies such as ADSL in most cases do not deliver adequate bandwidth to effectively use cloud services, even in small firms, particularly if employees need to use the internet for other functions (ITU, 2017). Alternative high-speed internet technologies - namely leased-line broadband - are expensive and so only an option for the very largest firms (Ofcom, 2009). [9]

This work contributes to an emerging part of the ICT literature that focuses on the impact of the organisation and geography of the firm. Previous work examining the impact of ICT on firm organisation 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), provider 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 fibre. There are a number of firm level studies across a variety of country

[8] Expected fibre speed is proxied by the local loop distance between the premise and the telephone exchange, we discuss the role of distance for fibre speeds later in the paper.

[9] A leased line connection cost roughly $400-$1,300 per month plus installation cost of roughly $650-$50,000 (Onestopclick, 2014).

contexts that examine the impact of ADSL on firm performance (Van Gaasbeck et al. 2008, Kolko 2012, Bertschek et al. 2013, Haller and Lyons 2015 and Grimes et al. 2012). Other studies examine the link between ADSL and skilled labour (Akerman et al. 2015), its effect on decision making across firms (Bloom et al. 2014a) and its impact on firm performance in rural regions (DeStefano, Kneller and Timmis 2018). More recently Fabling and Grimes (2016) use the rollout of ultrafast broadband to schools in New Zealand, exploiting the fact that these schools were enabled for different political and policy motives. Our approach improves on this by using zipcode level information on the date of fibre enablement alongside information on expected fibre speeds.

II. WHAT IS CLOUD?

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). The largest global cloud providers include Amazon Web Services, Microsoft Azure and Google Cloud Platform. Until recently, in order for a firm to benefit from digitalisation, significant investments in hardware and software were required. However, recently, there has been a shift in the nature of ICT adoption where firms are purchasing digital services (e.g. "cloud" computing) rather than making such investments themselves (OECD 2015).

The main characteristics of cloud computing which distinguishes it from traditional ICT services are the following: on demand availability of storage and data processing capacities, scalability that is infinite, quick deployment, negates irreversible upfront commitment, allows for pay-as-you-go short term contracts, enables network access to the cloud through standard devices like desktops, laptops and mobile phones (OECD 2014; NIST 2011, Armbrust et al. 2009, and Schubert et al. 2010).

One expected benefit of cloud computing is that it lowers entry barriers, leading to new employment opportunities and greater competition, particularly in sectors which previously relied heavily on fixed ICTs (OECD 2015; Etro 2010). The European Commission (2017) for example purports that between 2008 and 2020, the cloud could positively impact employment by 1.6 million jobs and the creation of 303,000 new businesses between 2015 and 2020 in the EU. The report concludes that in the next five years cloud computing may contribute an additional EUR 449 billion of revenue to GDP in the EU alone. Increased reliance on the cloud may also increase the impact of venture capital investment. In the past, a considerable proportion of equity investment was used to purchase essential IT equipment, however greater use of the cloud may incentivise investors to spread smaller amounts of equity to more firms. Renting hardware and software on demand may also enable firms to channel greater investments in essential areas for competitiveness such as R&D and marketing (OECD 2015; Columbus 2013). Digital platforms enabled by the cloud allow firms to scale their operations very quickly without the need for upfront investments, impacting the way they organise. Moreover, by avoiding the necessity to make quasi-irreversible investments in hardware, cloud can allow for greater flexibility and experimentation in the face of uncertainty (Jin and McElheran 2017). Since a considerable proportion of server and storage space used by firms is underutilized, greater reliance on the cloud is also expected to improve energy efficiency and lower firm utility costs (Masanet et al 2014).

III. ESTIMATION STRATEGY

This paper relies on an instrumental variable estimation to assess the various dimensions through which cloud computing effects firm growth and organisation. Our dependent variable y, refers to a number of firm outcome variables, including employment and sales per worker, but also measures of the concentration of activity, measured by the number of plants, plant deaths and plant births (per firm) and the geographic concentration of the firm.[10] We utilise firm and plant-level data from the Office for National Statistics (ONS), which is the UK Census Bureau equivalent. [11]

We introduce two new measures of geographic concentration to reflect various aspects of firm organisation. Our first measure simply reflects the number of different local authorities in which a firm's plants are located. Our second measure reflects the geographic dispersion of employees from the headquarters – specifically a weighted average distance between plants and their headquarters (weighted by the share of plant 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 plants from their headquarters, captures how far plants are located from the headquarters. Since we essentially estimate changes (i.e. we include firm fixed effects) we capture whether the plants that open/close are more, or less proximate to the headquarters. The covariance term measures how employment is distributed across plants. Specifically this term reflects the covariance between plant distance from the headquarters and plant employment. A positive covariance, shows that more distant plants are relatively larger in terms of employment, and a negative covariance shows that plants closer to the headquarters are larger. Again, since we estimate with firm fixed effects, we capture how the distribution of employment across plants changes over time. This covariance term has been popularised

[10] Number of plants, plant deaths and plant births are all expressed in logs. We add one to the number of plant deaths and births to avoid dropping zeroes.

[11] Data on firm and plant outcome and control variables, as well as firm location, is sourced from the UK business registry – the Business Structure Database. Information on cloud adoption (and later measures of IT per worker and Enterprise Resource Planning software adoption) are taken from the Ecommerce Survey. Later measures of investment in plant and machinery are taken from the Annual Respondent's Database.

by Olley and Pakes (1996) in productivity decompositions, for analysing whether more productive firms are typically larger.

Our parameter of interest, $cloud$ reflects the adoption of cloud computing by firm i at time t, which reflects the use of any cloud computing services over the internet. X_{it} represents a vector of controls including firm age, foreign ownership and size measured by the number of plants. Due to the availability of cloud data, we are restricted to three time periods for our analysis: 2008 (one year before the start of the fibre rollout), 2013 and 2015 (the latter two years for which we have data on firm-level cloud adoption). The e-commerce survey from the ONS on which this variable is measures includes 7 different types of cloud computing (data, storage, email, software, finance software, CRM and own software). From this we construct a single overall measure of cloud adoption by the firm. We provide evidence on these disaggregated types in Section IV.

We include firm (α_i) and year (α_t) fixed effects in all our estimations, meaning that our estimates are changes in firm outcomes driven by cloud adoption, removing any time invariant firm- industry- or location-specific confounding factors that might explain our findings. We focus on those firms born before the year 2008 and therefore had already chosen their location prior to the first announced of the UK fibre enablement program in October 2008 (see later discussion of the fibre rollout) – our results are robust to excluding firms born in 2007 and 2008.[12]

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

$$cloud_{it} = \alpha + \beta fibre_{it-1} + \beta fibre_{it-1} * dist_i + \gamma X_{it} + \boldsymbol{\varepsilon_{it}} \quad (2)$$

The instrumental variable framework relies on two instruments to predict firm cloud adoption: access to fibre broadband (lagged one period) signified by $fibre_{it-1}$ and as a proxy for fibre speeds, broadband availability interacted with firm distance from the telephone exchange, $fibre_{it-1} * dist$ (see next section).[13] The fibre enablement variable $fibre_{it-1}$

[12] Due to the nature of the rollout program, the sample of firms in this analysis tend to be in urban settings.

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

indicates whether a firm is connected to a part of the telecommunication infrastructure that is enabled with fibre last period signified by $fibre_{it-1} = 1$ or if the firm is connected to a non-enabled exchange $fibre_{it-1} = 0$.[14]

Descriptive statistics

We provide summary statistics on the adoption of cloud computing in Table 1 and Table 2 for the pooled sample across all years. In these tables we report our main measure of cloud, along with two commonly used cloud types, those for email and storage. The table shows that just under 25% of firms use cloud within the sample period, with the figures for cloud for data storage, at 11%, and email, at 13%, somewhat lower than this. It is important to note that the figures 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 in Table 2 we report their values in 2013 and 2015. The statistics in Table 2 relate to adoption rather than changes in the sample of firms we report these summary statistics for a balanced panel of firms. As expected the adoption of cloud technologies rise over time. By 2013 the rate of cloud adoption is 41%, rising to 51% just two years later. The use of cloud for data and for email rise in a similar fashion.

Table 1 Summary Statistics of Cloud Adoption

Variable	mean	standard deviation	observations
Cloud	0.247	0.431	12,860
Cloud Data	0.105	0.306	12,860
Cloud Email	0.132	0.339	12,860

[14] The instruments are lagged one year to allow for the time needed to adjust to fibre enablement and cloud adoption.

Table 2 Summary Statistics Across Time

Variable	2008 mean	2008 st.dev.	2013 mean	2013 st.dev.	2015 mean	2015 st.dev.	Obs.
Cloud	0.000	0.000	0.408	0.491	0.509	0.500	12,860
Cloud Data	0.000	0.000	0.174	0.379	0.215	0.411	12,860
Cloud Email	0.000	0.000	0.193	0.395	0.299	0.458	12,860

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.

In terms of other variables, the firms in our sample are typically fairly small. This is despite the E-commerce survey being a stratified random sample skewed towards medium and larger firms (See Table 3). For example, the mean firm has log employment of 5 (equivalent to around 110 employees), has 31 plants (although the median is 2, i.e. 1 in addition to the headquarters). In terms of geographic dispersion, the mean firm has plants on average 55km away (those single plant firms are clearly of zero distance). The negative covariance term shows that plants further from the headquarters tend to have lower employment, as is expected. Turning to our instruments, which we discuss further in the next section, on average across all periods 0.49 firms have fibre availability and firms are 0.62 km from their nearest telephone exchange (See Table 3).

Table 3: Summary Statistics of Other Variables

Variable	mean	Sd	Obs.
(Log) Employment	4.72	2.12	12810
Multiplant	0.537	0.50	12715
No. of plants	31.01	214.39	12715
Number of plant deaths	3.40	33.82	12715
Number of plant births	3.60	43.95	12715
Weighted average distance plants headquarter (km)	40.47	71.59	12843
Unweighted average distance plants headquarter (km)	54.41	83.23	12698
Covariance plant distance-plant employment	-13.92	38.40	12843
Fibre enabled	0.52	0.50	12860
Number of local authorities	12.91	47.71	12715
Foreign owned	0.202	0.401	12715
Log age	3.087	0.661	12715
Urban	0.886	0.317	12715
Fibre enabled	0.489	0.500	12715
Cable Distance of fibre enabled	0.624	0.855	12715

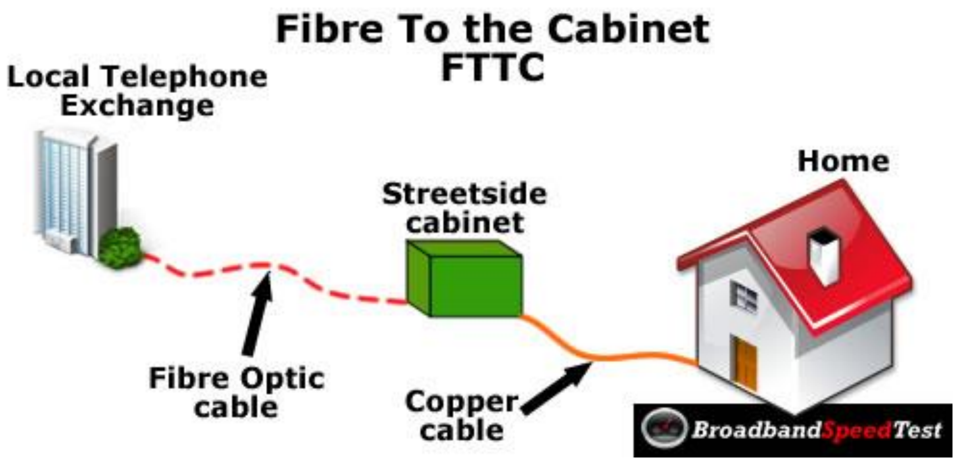
IV. FIBRE BROADBAND INSTRUMENTAL VARIABLES

What is Fibre?

In the UK, fibre is the main source of high-speed broadband and like its main predecessor, ADSL it relies heavily on the telephone exchange network, using pre-existing exchange boxes and cabinets to deliver fibre services. The most prevalent form of fibre in the UK, fibre to the cabinet (FTTC) employs a fibre optic cable between the exchange box and the cabinet rather than using the pre-existing cooper cable (See Figure 1). Since fibre cables are more efficient in transmitting data, fibre broadband offers faster upload and download speeds than ADSL broadband. For example, on average in the UK, FTTC offers speeds of roughly 33.4 mbps while ADSL speeds are roughly 8.0 mbps (BT Openreach, 2017).

A small minority of establishments in the UK have another version of fibre called fibre to the premise (FTTP), in which the fibre network runs between the exchange and the local cabinet and from the cabinet to the premises. BT piloted FTTP towards the end of the rollout period (from phase 8 (out of 11)). While we do not have precise data on premises that have FTTP, they represent a small share of UK businesses. For example, by the end of 2013, BT had enabled connections for 2.4 million households and businesses through FTTC, but only 0.05% were enabled for FTTP (Point Topic, 2014).

Figure 1: Telephone network of FTTC



Fibre enablement

Our first instrument, fibre availability, relies on zipcode level data detailing the rollout of fibre broadband in the UK. Our dataset contains enablement information from the start of the UK rollout program, in 2009, to its completion in 2014 covering predominately urban regions of the country (See Figure 2-5). The program accounts for roughly 30% of all exchanges and 80% of businesses in the UK.[15] The rollout scheme was first announced in October 2008, with a pilot phase of 3 exchanges to be enabled with fibre. These first exchanges were enabled in 2009, as reflected in Figure 2. Following the pilot, BT announced a £2.5bn program intended to rollout of fibre to cover 66% of the UK homes and businesses by spring 2014. We exclude exchanges in Northern Ireland and Cornwall as these were enabled in a joint-venture with BT, with limited data on exchange enablement dates.

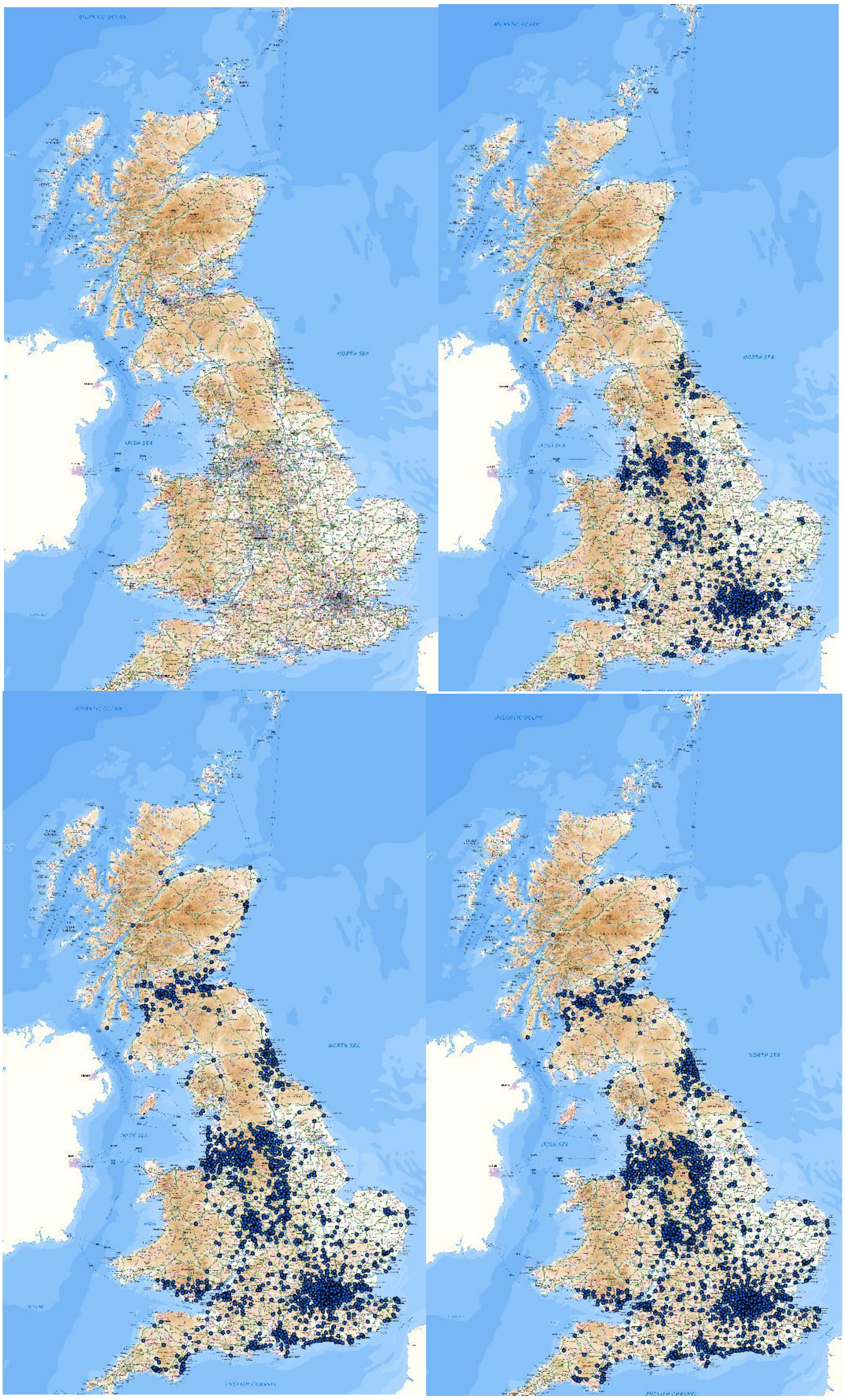
The set of exchanges to be part of the fibre program was explicitly chosen by BT as part of a commercial decision. Those locations and firms in those locations that are part of the fibre program are substantially different to those that are not part of the program. The exchanges that were chosen to be part of the program are typically in urban locations, with a larger agglomeration of households and businesses connected to the exchange. Accordingly for our analyses we exclude all firms connected to exchanges outside the BT fibre program, and focus entirely on the timing of enablement of exchanges *within* the BT program. That is, for this instrument we rely on the cross-time variation in the date of enablement amongst exchanges that were fibre enabled by BT by the end of the period. As we show, when we focus on exchanges in this way there is no evidence that BT enabled larger exchanges (measured by the number of household or business connections) earlier and there is no correlation between these instruments and measures of firm performance in the pre-enablement period. A secondary reason for this choice is that from 2014, some local fibre schemes began to enable some exchanges outside the BT fibre 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 fibre access in later years.

[15] During this time, the number of exchanges equipped with fibre increased from 159 exchanges in 2010 to 1627 exchanges by the end of 2014 (Figures 2 to 5). Note some rural and local fibre enablement schemes have commenced after 2014.

The UK rollout consisted of 11 phases, where the timing of the rollout was determined by a number of factors. Give the size of a national telecommunication infrastructure in the UK, timing of enablement was 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 care before fibre activation. In addition, several exchanges were scheduled to be enabled much earlier than they were for a variety of reasons. Two exchanges in Kensington Gardens and Chelsea were initially scheduled to be enabled as part of phase 7b (April 2011), but were only eventually included in one of the last phases, phase 11a (February 2013). The enablement was delayed because local residents disliked the proposed colour scheme of the fibre-enabled cabinets.

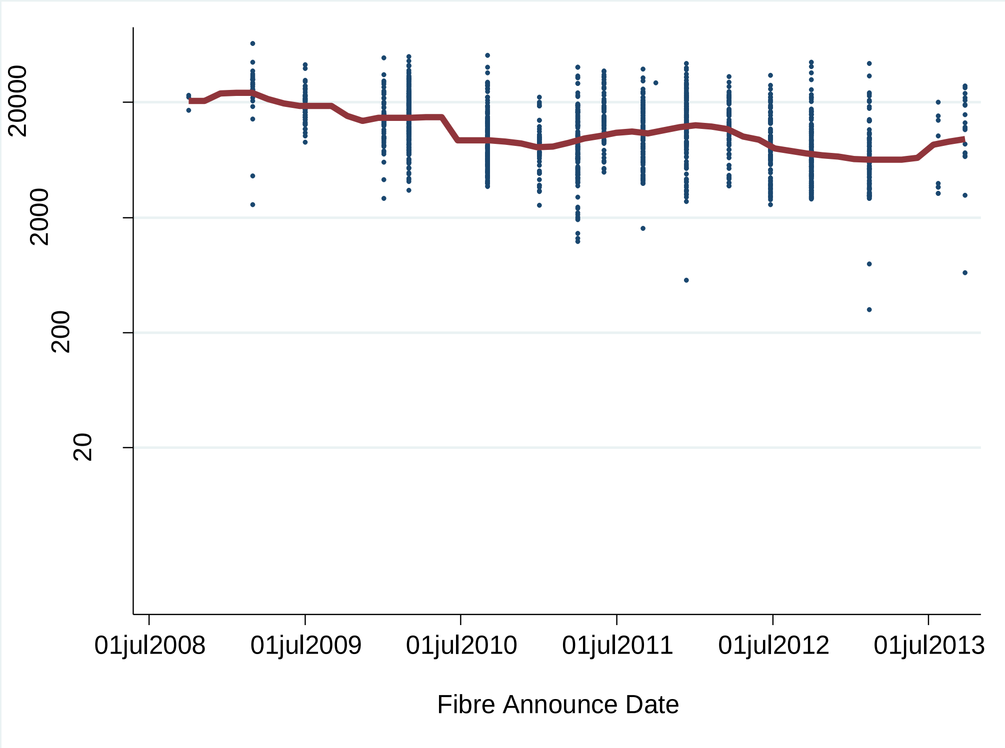
The timing of fibre enablement does not appear to be strongly linked with the size of the exchange, measured by the number of households and firms connected to the exchange. Figure 6 shows the timing of fibre rollout by exchange size. Firstly there is a large spread of exchanges of very different sizes planned to be enabled at the same point. Secondly, there is a weak downward trend, for instance, exchanges announced at the end of 2010 are smaller than both exchanges announced earlier and later - in 2009 and 2011.

Figures 2-5: Location of Fibre Enabled Exchanges by 2009, 2011, 2013, 2014



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

Figure 6: Timing of Fibre Rollout and Exchange Size



Notes: Points represent the fibre announcement date and exchange size of an individual exchanges that are part of the BT fibre programs. A best fit polyline has been added for clarity. Announcement dates have been plotted rather than enablement dates (which show similarly), since enablement dates are only available by calendar year for some exchanges.

Fibre speeds

Our second instrument exploits the fact that expected fibre speeds decline with distance to the telephone exchange. Broadband is a distance dependent technology, therefore the greater the distance the firm is located relative to the exchange box to which it is connected, the slower are its internet speeds (BT, 2009). Figure 7 below illustrates that fibre 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 4 illustrates the differences in the crow-flies distances to the exchange in our sample. These differences suggest disparities in fibre speed given the distance dependency of the technology. For example, the crow-flies distance between the average firm and their exchange is roughly 1.3 kilometres where the crow-flies distance of the top 25% around 500 meters and the bottom 75% with a cable length of roughly 1,800 meters. It is also important to note that since distance is measured as the crow flies, they are likely to underestimate the actual distance of the local loop cable running between the premise and the exchange box, since cables do not travel in a straight line but can follow local terrain and pre-existing infrastructure.

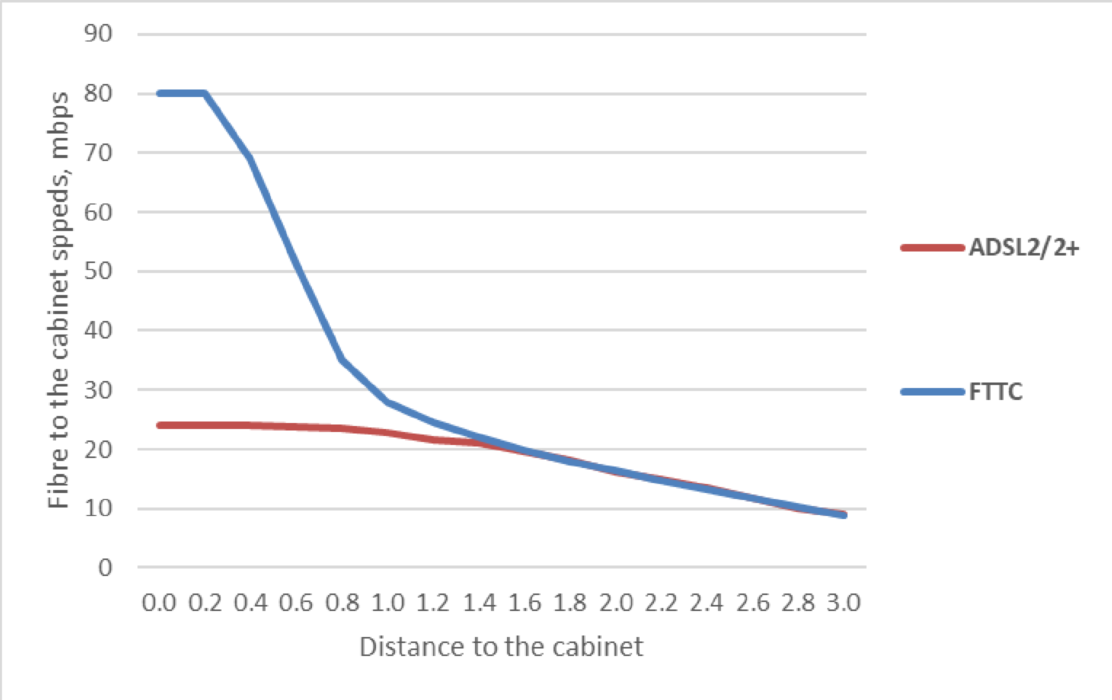
Table 4: Cable distance to the local telephone exchange

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 7. Based on engineering tests, these figures show that for a cable distance of 2,000 meters from the cabinet FTTC connections speeds are roughly half of those were the cable distance 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.[16] Whereas in contrast ADSL broadband speeds decay much more gradually and are possible up to 5,500 metres from the telephone exchange (see DeStefano, Kneller and Timmis, 2018). Therefore, fibre provides a substantial improvement over the earlier technology (ADSL broadband) only over very short distances, within 1000 metres of the cabinet.

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

Figure 7: Fibre to the cabinet connection (FTTC) speeds and distance to the cabinet



Notes: Here we report expected fibre 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 further than 3 kilometres as these are extremely rare (Heath, 2013).

Firm distance from the exchange is arguably exogenous to firm performance. The location of the telephone exchanges is based on the pre-existing telephone infrastructure dating back in some cases as far as the 19^{th} century. The main purpose of the telecom network was originally to enable the population to use a telephone. Importantly, the use of load coils allows phone calls to maintain acceptable quality at distances anywhere between 5 kilometres to as far as 16 kilometres (Macassey, 1985). Distance from the exchange was therefore less of an issue for the telephone technology the network was initially built for than for FTTC. Firms born before the development of broadband would not have chosen an optimal location to the exchange based on a technology that had yet to be invented. Cost restrictions and technical aspects prevented BT from digging up parts of the network to move existing cooper cables and exchanges closer to certain premises. Moreover, limited inter-connections of the fibre backbone prevented consumers from switching to a different telephone exchange.

Instrument Relevance

In Table 5 we provide evidence that fibre enablement and cable distances help to predict the adoption of cloud. 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). We use the latter to test for any non-linearities within the data. Regressions 1 and 3 include firm and year fixed effects, while regressions 2 and 4 include add firm control variables.

In all cases we find the expected relationships. Across all four regressions we find that firms attached to fibre 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 1 kilometre 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 metres 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 metres from the exchange, followed by those between 500 and 1000 metres. 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 fibre enabled or not. We note that this result contrasts with earlier research using ADSL broadband, which finds the effect of ADSL on ICT capital investment for much longer distances, even for distances exceeding 3500 metres (DeStefano, Kneller and Timmis, 2016). These results continue to hold when we add control variables (regressions 2 and 4). Of the control variables we find that firms that are foreign owned and are younger are more likely to use cloud computing.

Table 5 First stage enablement and distance on cloud adoption

Dependent variable: Cloud	(1)	(2)	(3)	(4)
Time period	2008, 2013, 2015	2008, 2013, 2015	2008, 2013, 2015	2008, 2013, 2015
Fibre Enablement	0.119***	0.120***	0.060***	0.061***
	(0.021)	(0.021)	(0.023)	(0.023)
Fibre*Distance	-0.031***	-0.031***		
	(0.008)	(0.009)		
Fibre, Dist. < 500 metres			0.063***	0.063***
			(0.021)	(0.021)
Fibre, Dist. 500-1000 metres			0.047**	0.048**
			(0.020)	(0.020)
Fibre, Dist. 1000-1500 metres			-0.020	-0.020
			(0.021)	(0.021)
Fibre, Dist. 1500-2000 metres			0.006	0.006
			(0.022)	(0.022)
Control variables				
Multi-plant		-0.002		-0.002
		(0.19)		(0.019)
Foreign owned		0.040*		0.039*
		(0.023)		(0.023)
Log age		-0.059***		-0.060***
		(0.018)		(0.018)
Observations	12,860	12,860	12,860	12,860

*Notes: 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.*

The above evidence suggests that fibre broadband access is correlated with cloud adoption. In fact there are a number of cloud services available to firms, where for some of these the faster connection speeds offered by fibre broadband may be less relevant. For example, we would expect the bandwidth offered by connection speeds to be more important for tasks such as data processing and storage. We explore this point further in Table 6 by separating firms cloud adoption into the 7 different types available within the data, where this include for email, data processing, storage and software.

Across the table as a whole we continue to find that cloud adoption, of whatever type, is positively related to enablement of the local telephone exchange and negatively with cable distance to the exchange. As expected, there is also variation across these regressions. Fibre is a stronger predictor for types of cloud where the speed of connection is likely to matter, such as data, storage and less with types where than are less speed dependent, such as email.

This is apparent both in terms of the magnitude of the coefficients on the enablement and distance variable and the level of their statistical significance. The weakest effects of distance are found for finance software and CRM software, while the relationship with cloud for software is not statistically significant.[17]

[17] In this remainder of the paper, our treatment is cloud computing rather than a disaggregated measure of services such as data, storage, email, software and so on. This approach follows the ICT literature which makes similar assumptions based on the view that many of these technologies are complementary (Cordona et al 2013 and Draca et al 2006).

Table 6: Types of cloud services

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable	Cloud email	Cloud software	Cloud data	Cloud storage	Cloud finance software	Cloud CRM	Cloud own software
Specification	IV	IV	IV	IV	IV	IV	IV
Fibre	0.062***	0.049***	0.086***	0.089***	0.059***	0.046***	0.050***
	(0.018)	(0.014)	(0.017)	(0.019)	(0.013)	(0.015)	(0.013)
Fibre*distance	-0.014**	-0.006	-0.028***	-0.020***	-0.009*	-0.011*	-0.011**
	(0.007)	(0.006)	(0.006)	(0.007)	(0.005)	(0.006)	(0.005)
Observations	12860	12860	12860	12860	12860	12860	12860

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Instrument Validity

The exclusion restrictions for the validity of our instrument require that fibre enablement and the distance from the telephone exchange have no direct effect on our firm performance measures independent of its relationship with cloud. While the timing of enablement by British Telecom might be considered outside of the control of individual firm, the timing of an individual exchange was a commercial decision. One potential threat to this validity might therefore occur if fibre broadband was targeted at those firms already performing better because of some unobservable region, industry or firm characteristic. That there are many firms connected to the same exchange of course reduces this possibility.

Fibre enablement was targeted initially at urban exchanges. These exchanges are characterised by shorter local loops and are attached to greater numbers of households, which are features that are likely to be correlated with agglomeration or other geographic factors. Agglomerations of businesses are typically more productive (Combes et al., 2012), and are more likely to use new technologies, such as ICT, but also possess greater management skills (Glaeser and Resseger, 2010; Puga, 2010). It therefore follows that agglomeration may help predict shorter local loop lengths and fibre enablement and be correlated with measures of firm performance.

A 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 centres and concentrations of residential property and, to aid with the laying of cabling, they were often also located near major road junctions. The local characteristics that helped to determine the commercial decision by BT of where to locate its telephone exchange may be similar to those that affect firm location decisions. Plausibly firms may also wish to be close to commercial centres 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 there are reasons to doubt the validity of these arguments in our setting. Distance had no bearing on the quality of telephone connections and it would seem plausible that firms did not choose their locations to be close to the telephone exchange. Moreover, firms born before the development of broadband would not have chosen an optimal location to the exchange based on a technology that had yet to be invented. Cost restrictions and technical aspects prevented BT from digging up parts of the network to move existing cables and exchanges closer to certain premises. Also, limited inter-connections of the fibre backbone prevented consumers from switching to a different telephone exchange. Nevertheless, we remove the effect of time invariant agglomeration, industry or firm specific factors in the analysis through the inclusion of firm fixed effects.

These fixed effects do not remove the possibility that fibre enablement was targeted at telephone exchanges that were expected to grow quickly in the future. This suggests a need to explore the potential for a correlation between the characteristics of firms and unobserved geographic factors in addition to the timing of enablement. To consider this we exploit the availability of pre-enablement data to test for a correlation between ex-ante observable measures of firm performance and future fibre enablement (See Table 7). We find that there are no significant correlations with the timing of fibre enablement and ex-ante firm performance measures including changes in sales, employment or sales per workers. Moreover we also find no statistical link between firm distance to the exchange and their ex-ante performance, consistent with an interpretation that our instruments are valid.

Table 7: Ex Ante characteristics

	(1) Fibre enablement	(2) Fibre enablement	(3) Fibre enablement	(4) Exchange distance	(5) Exchange distance	(6) 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-plant	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.*

V. MAIN RESULTS

Firm Scale and Plant Organisation

In the baseline results of Table 8, we present instrumental variable estimates of the effect of cloud adoption on firm growth, measured by firm employment, and the distribution of activity across plants, measured by the number of plants, number of plant births and deaths.[18]

There are strong reasons to expect that the impacts of cloud may differ between younger and incumbent firms. For young firms cloud offers the possibility to scale quickly and to remove the financial constraints that may previously have inhibited large scale and rapid investments in ICT, in particular when demand is uncertain. Older firms in contrast, are likely to embed organisational and management structures suited to previous technologies and so cloud offers the possibility to enact cost efficiencies and force through restructuring.

We explore treatment heterogeneity allowing for separate effects of cloud on new and incumbent firms. We capture this using dummy variable denoting if a firm was aged 5 years old or younger in 2008. We interact both our cloud variable and our fibre instruments with the age dummy. The interaction terms are expressed such that they estimate the effect for young and incumbent firms separately, and therefore the estimated coefficient for the relevant group is being tested against the null of a zero effect.[19]

In the first stage, we find consistent with the previous section that fibre enablement significantly predicts cloud adoption, even allowing for differences across young and incumbent firms. In the first stage regression for incumbent firms we find that being attached to a fibre enabled exchange increases the probability of adopting cloud by 14%, while it is 47% for young firms. We also find that each kilometre from the exchange reduces the propensity to adopt cloud by just over 2.4% for incumbent firms and by 9.5% by for young firms. The first stage F-statistic of around 18, confirms the predictive power of the

[18] We add one to the number of plant deaths and births is expressed, to avoid dropping zeroes.
[19] As a robustness test we also change the definition of a young firms to those between the age of 0 and 10 in 2008 and the results are consistent to those in Table 9.

instruments. The results also comfortably pass tests for overidentification, 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 firm scale, measured by employment, for young firms. In contrast, the estimated effect for incumbent firms is not statistically significant. As our data are measured for the years 2008, 2013 and 2015, this equates to approximately a 13% annual increase in employment for young firms over this 7 year time period. [20]

There is also evidence of differences for the various measures of fragmentation.[21] For younger firms who adopt cloud because of fibre, we find they are significantly less likely to become multi-plant firms. Conversely for incumbent firms we find no effect on the probability of becoming multi-plant, but some evidence of experimentation through the number of plants and the closure of plants.[22]

[20] Following the evidence reported in Table 8 of a stronger effect of the instruments on the use of cloud for data and for storage, in Appendix Table A1 we report results using a measure of cloud for these groups only. The results are very similar except that we find a weakly significant effect on employment for incumbent firms.

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

[22] In order to ensure that our results are not somehow driven by young firms self-selecting into areas before the rollout, rerun the results using data for 2006 as the baseline year. These results are reported in Table A2 in the Appendix. The results found mirror those in Table 8. We have also rerun these results excluding firms that were born in 2007 and 2008. Again all of the main findings continue to hold. These results are available on request.

Table 8: Impact of cloud on firm growth: young vs incumbents

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Labour productivity	Multi-plant	Log No. Plants	Log No. Plant Deaths	Log No. Plant Births
Specification	IV	IV	IV	IV	IV	IV
Cloud -incumbent	0.470	-0.153	-0.012	0.205*	0.617***	0.311
	(0.299)	(0.356)	(0.120)	(0.111)	(0.211)	(0.233)
Cloud-young	1.059***	0.276	-0.339**	0.024	0.019	-0.050
	(0.362)	(0.416)	(0.133)	(0.121)	(0.207)	(0.238)
First stage Cloud- Incumbent						
Fibre -incumbent	0.138***	0.137***	0.137***	0.137***	0.137***	0.137***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Fibre-young	-0.283***	-0.282***	-0.284***	-0.282***	-0.282***	-0.282***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Fibre*distance-incumbent	-0.024***	-0.023***	-0.023***	-0.023***	-0.023***	-0.023***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Fibre*distance-young	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
First stage Cloud-Young						
Fibre -incumbent	-0.024***	-0.025***	-0.024***	-0.024***	-0.024***	-0.024***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Fibre-young	0.466***	0.466***	0.468***	0.466***	0.466***	0.466***
	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)
Fibre*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)
Fibre*distance-young	-0.095***	-0.096***	-0.096***	-0.096***	-0.096***	-0.096***
	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Observations	12800	12807	12860	12860	12860	12860
Cragg-Donald F	18.38	18.32	18.57	18.56	18.56	18.56
Kleibergen-Paap F	11.10	11.12	11.28	11.27	11.27	11.27
J-stat(p-value)	0.24	0.80	0.27	0.17	0.59	0.99

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Heterogeneity

In Table 8 there is evidence that the effects of cloud technologies differ between young and incumbent firms. In Table 9 we consider whether these effects also differ by the size of the firm. We repeat regressions 1 and 2, for employment and labour productivity respectively, but now interact the adoption of cloud for young firms with the initial employment of the firm (measured in 2008). The employment variable is centred on the mean employment for young firms (7.8 employees), such that the cloud-young coefficient provides the effect of cloud for the average firm, and the interaction with initial employment shows how this effect as initial employment moves above or below the mean.

The results show some interesting differences across the two regressions. In regression 1 in Table 9 we continue to find that for the average young firm the adoption of cloud technologies are associated with faster employment growth, but with no effect on labour productivity. As the initial size of the firm increases this employment effect is smaller, the interaction term is negative and statistically significant. In contrast, as the initial size of the firm increases above the mean of 7.8 employees there are positive effects on labour productivity.[23]

[23] In Table A3 the Appendix we explore whether there are differences according to the size of the firm by including interaction terms for small and large firms.

Table 9: heterogeneity using mean centred initial employment

	(1)	(2)
Dependent variable	Size	Labour productivity
Specification	IV	IV
Cloud - incumbent	0.365	-0.065
	(0.318)	(0.364)
Cloud-young	1.349***	0.211
	(0.376)	(0.429)
Cloud-young-initial employment	-0.642***	0.349***
	(0.076)	(0.091)
Observations	12554	12503
Cragg-Donald F	11.91	11.80
Kleibergen-Paap F	7.14	7.07
J-stat (p-value)	0.13	0.62

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Plant Organisation and Plant Fibre Access

In the previous section we found that incumbent firms are more likely to close plants as a result of using cloud computing services. In this section we take the analysis down to the level of the plant, and examine which plants are closed, and in particular whether the ability of the plant to access fibre is a key determinant of this. Much of the anecdotal evidence suggests that cloud can be used by firms to restructure, in particular, to take advantage of the new possibilities cloud brings to access large volumes of data and computer processing throughout the organisation. Given the fact that fibre is a pre-requisite for cloud use, this is only fully possible if all parts of the organisation have high-speed internet access. This may suggest that firms are more likely to close plants that do not have access to fibre.

To supplement the prior analysis at the firm-level, we add additional information on whether the plant has access to cloud and fibre. We focus on plants without cloud access, since we want to capture possible plant exit, and create an indicator variable equal to 1 if either the firm has not adopted cloud or the firm has adopted cloud and the plant has no fibre access. We instrument this plant cloud measure, with the same type of fibre access variables but now measured at the plant level. We continue to include firm (headquarter) cloud adoption and fibre availability as in the prior section. Therefore, in these new regressions for plant closure we have both headquarters and plant treatment variables and two sets of headquarters and plant fibre instruments – to examine their differential effects.

In the first stage regressions we find evidence that headquarters are more much likely to adopt cloud when they have access to fibre internet connections and shorter distances to the exchange. Headquarters are also more likely to adopt cloud when their plants have fibre access, which is consistent with the returns to cloud adoption being greater when it is possible to be used more extensively throughout the organisation. Similarly, plants are more likely to adopt cloud (less likely not to have cloud) when the infrastructure suggests fast internet connections for the plant and the headquarters (cable distances are shorter).[24]

Turning to the second stage, we find that headquarter cloud adoption does not seem to have a significant impact on these plant-level regressions (contrasting the earlier results for incumbents) – which probably reflects the inclusion of plant cloud variables and that we do not restrict the analysis to incumbents. However, plants that do not have cloud are significantly more likely to exit (at t+1). Plants without cloud access, because they do not have fibre, are 0.4% more likely to exit than those with fibre access. Clearly this is a fairly small coefficient, which may in part reflect our use of a one year exit probability. These results along with those in Table 8 further confirm that cloud technologies along the development of fibre broadband infrastructure have a significant effect on the restructuring of firms.

[24] There are just 126 firm/plant-year observations in which the plant gains access to fibre before the firm. Given this small number we do not explore this possibility in the regressions.

Table 10: Plant Level Regressions

	(1)	(2)
Dependent variable	Plant Exit Propensity	Plant Exit Propensity
Specification	IV	IV
HQ-Cloud	-0.013	
	(0.023)	
Plant Without Cloud	0.004*	0.004**
	(0.002)	(0.002)
HQ Cloud		
HQ Fibre	0.031***	
	(0.004)	
Plant Fibre	0.015***	
	(0.003)	
HQ Fibre* HQ distance	-0.032***	
	(0.002)	
Plant Fibre*Plant distance	-0.003*	
	(0.002)	
Plant Without Cloud		
HQ Fibre	-0.027***	-0.027***
	(0.003)	(0.003)
Plant Fibre	-0.734***	-0.734***
	(0.002)	(0.002)
HQ Fibre*HQ distance	0.028***	0.028***
	(0.001)	(0.001)
Plant Fibre*Plant distance	0.002	0.002
	(0.002)	(0.002)
Observations	27,676	27,676
Cragg-Donald F	156.70	43620.51
Kleibergen-Paap F	99.41	52118.66

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Geographic Organisation

Cloud is also likely to impact the how firms disperse geographically. The reduced reliance on centralised IT departments and facilitating better information access across the organisation may enable greater geographic dispersion of firm activity. 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). Table 11 examines the impact of cloud on firm geographic dispersion of firm activity.

We introduce different measures of the geographic dispersion of firm activity. Our primary measure reflects the geographic dispersion of employees from the headquarters – a weighted average distance between plants and their headquarters (weighted by the share of plant employment in firm employment). We decompose the weighted average distance variable into two terms – an unweighted average distance and a distance-employment covariance term. The unweighted average distance of plants from their headquarters, captures how far plants are located from the headquarters. The covariance term measures how employment is distributed across more proximate or more remote plants. A positive covariance, shows that further plants are larger in terms of employment, and a negative covariance shows closer plants are larger. Finally, we add a measure of the number of local authorities (equivalent to counties in the US) in which the firm has plants in. Again, since we estimate with firm fixed effects, we capture how the geographic distribution of activity changes for the firm over time. Equations detailing the geographic dispersion measures can be found in the Appendix.[25]

In line with the results from Table 8, which indicated employment but few other effects, for young firms we find little impact on geographic dispersion. This is very different for incumbent firms. The weighted average distance shows how far the average employee works (at their plant) from the headquarters. Cloud leads to the average employee working 24km further from their headquarters. We decompose the weighted average distance into a covariance term and unweighted average distance of plants from the headquarters. For incumbents we fail to find evidence that they are systematically more likely to close or open further or more proximate plants – as reflected in the unweighted distance. Instead, it is

[25] In these regressions we include all firms. We report versions only for incumbent firms in Appendix Table A4.

entirely that the distribution of employment shifts towards more distant plants, reflected in the positive covariance term. Finally, we find that incumbents are more likely to operate in more local authorities.

These results suggest very different mechanisms at work for younger and older firms. Perhaps cloud leads to a restructuring of incumbent organisations, closing more proximate plants and decentralising activity to local plants away from the headquarters, even relocating managers or other workers within the firm. Whereas for younger firms we find no such geographic reorganisation – 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 networks.

That there are differences across firms from the same technology also marks cloud out as different compared to previous forms of ICT. A well-known study by Kolko (2012) finds a positive relationship between broadband expansion and economic growth in cities, especially in industries that rely more on information technology. Ioannides et al. (2007) take a very different approach to this question, testing directly whether the size of cities have become more or less similar over time.[2] They find that ICT leads to a less concentrated distribution of city sizes suggesting that it acts to disperse economic activity across geography. This approach is close in spirit to work by Sivitanidou (1997) who found that between 1989 and 1994 the office-commercial land value gradients within Los Angeles flattened. This also suggests that the recent information revolution had weakened the attractiveness of large business centres to office-commercial activities, resulting in the increasingly dispersed patterns of business locations. This dispersion of economic activity would be consistent with increased activity, including investment in plants away from the headquarters of the firm. We find a more complex picture for cloud on incumbent firms and no evidence of this type for young firms.

Table 11 Impact of cloud on geographic dispersion

Dependent variable	Avg distance (weighted)	Avg distance (unweighted)	Covariance	No. Local authorities
Cloud -incumbent	24.090**	4.322	19.769**	0.250**
	(10.267)	(11.918)	(10.070)	(0.114)
Cloud-young	15.667	5.402	10.265	0.107
	(11.633)	(12.774)	(10.059)	(0.129)
First stage Cloud- Incumbent				
Fibre -incumbent	0.137***	0.137***	0.137***	0.137***
	(0.022)	(0.022)	(0.022)	(0.022)
Fibre-young	-0.282***	-0.282***	-0.282***	-0.282***
	(0.021)	(0.021)	(0.021)	(0.021)
Fibre*distance-incumbent	-0.023***	-0.023***	-0.023***	-0.023***
	(0.009)	(0.009)	(0.009)	(0.009)
Fibre*distance-young	-0.003	-0.003	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)
First stage Cloud-Young				
Fibre -incumbent	-0.025***	-0.025***	-0.025***	-0.024***
	(0.005)	(0.005)	(0.005)	(0.005)
Fibre-young	0.469***	0.469***	0.469***	0.466***
	(0.039)	(0.039)	(0.039)	(0.039)
Fibre*distance-incumbent	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Fibre*distance-young	-0.096***	-0.096***	-0.096***	-0.096***
	(0.023)	(0.023)	(0.023)	(0.023)
Observations	12834	12834	12834	12860
Cragg-Donald F	18.31	18.31	18.31	18.56
Kleibergen-Paap F	11.17	11.17	11.17	11.27
J-stat (p-value)	0.97	0.53	0.32	0.96

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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 plants from their headquarters, where the weights are the share of plant employment in firm employment. The covariance term measures the correlation between plant employment and distance from the headquarters, i.e. whether further plants are larger (a positive covariance), or closer plants 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 plants located.*

VI. CONCLUSIONS

This paper presents new evidence on the impact of cloud adoption, on firm growth and how firms grow. We use novel instrumental variables on zipcode level availability and expected speeds (using local loop distances) of fibre broadband to predict firm cloud adoption. These instruments are relevant for the adoption of cloud technologies. However fibre only has predictive power over those short local loop distances (within 1000 metres) where there is a substantial speed improvement over prior ADSL broadband technology. The instruments predict adoption in the types of digital services for which fibre 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 fibre 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 for younger and incumbent firms. Younger firms that adopt cloud are more likely to increase employment and become more productive (for certain firms), but are less likely to have multiple plants. For incumbent firms that adopt cloud we find no scale or productivity impact, but instead they are more likely to reorganise activity, by closing plants and moving employment further from the headquarters and across more local authorities. An important characteristic determining whether a plant closes is if they do not have access to fibre. Cloud along with the fibre infrastructure therefore appears to enable young firms to scale without mass while incumbents use the technology to reorganise and reduce their cost structure.

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 fibre broadband. In fact for most cloud services, fibre 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). However other areas which may require renewed consideration are around traditional tax schemes and incentive policies targeted towards investments, which we hope to address in the near future.

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APPENDIX

Weighted average distance of plants 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 plants from their headquarters, and $s_p = \frac{emp_p}{emp_f}$ is the share of plant 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 plants from the headquarters

Intuition: distance of the mean plant 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 plants from their headquarters, and N_f is the number of plants of the firm.

Covariance between plant employment and plant distance from the headquarters

Intuition: measures how employment is distributed across plants by their proximity - are further plants larger (+ve covariance) or closer plants 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 plant employment. Other terms are defined as above.

Table A1: 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 per worker	Multi plant	Log No.Plants	Log No. Plant Deaths	Log No. Plant Births
Specification	IV	IV	IV	IV	IV	IV
Cloud-incumbent	0.581*	-0.175	-0.015	0.232*	0.734***	0.233
	(0.348)	(0.405)	(0.138)	(0.131)	(0.259)	(0.238)
Cloud-young	1.378***	0.401	-0.456***	-0.008	-0.067	0.036
	(0.450)	(0.500)	(0.160)	(0.149)	(0.258)	(0.247)
First stage Cloud- Incumbent						
Fibre -incumbent	0.120***	0.117***	0.120***	0.120***	0.120***	0.120***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Fibre-young	-0.199***	-0.199***	-0.198***	-0.198***	-0.198***	-0.198***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Fibre*distance-incumbent	-0.022***	-0.021***	-0.021***	-0.021***	-0.021***	-0.021***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Fibre*distance-young	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
First stage Cloud-Young						
Fibre -incumbent	-0.018***	-0.018***	-0.018***	-0.018***	-0.018***	-0.018***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Fibre-young	0.348***	0.348***	0.350***	0.349***	0.349***	0.349***
	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)
Fibre*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)
Fibre*distance-young	-0.074***	-0.075***	-0.075***	-0.075***	-0.075***	-0.075***
	(0.023)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Observations	12800.00	12807.00	12860.00	12860.00	12860.00	12860.00
Cragg-Donald F	14.90	14.52	15.11	15.09	15.09	15.09
Kleibergen-Paap F	9.00	8.83	9.18	9.16	9.16	9.16
J-stat(p-value)	0.31	0.79	0.27	0.15	0.62	0.96

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Table A2 Impact of cloud on firm growth: young vs incumbents. Use of 2006 data

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Log Sales per worker	Multi plant	Log No. Plants	Log No. Plant Deaths	Log No. Plant Births
Specification	IV	IV	IV	IV	IV	IV
Cloud-incumbent	0.851**	-0.687	0.275**	0.058	0.625***	0.081
	(0.344)	(0.440)	(0.134)	(0.122)	(0.201)	(0.221)
Cloud-young	1.579***	-0.105	-0.172	-0.102	0.295	0.035
	(0.401)	(0.511)	(0.156)	(0.129)	(0.207)	(0.230)
First stage Cloud- Incumbent						
Fibre -incumbent	0.138***	0.136***	0.138***	0.137***	0.137***	0.137***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Fibre-young	-0.292***	-0.292***	-0.294***	-0.290***	-0.290***	-0.290***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Fibre*distance-incumbent	-0.021**	-0.020**	-0.020**	-0.020**	-0.020**	-0.020**
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Fibre*distance-young	-0.003	-0.002	-0.002	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
First stage Cloud-Young						
Fibre -incumbent	-0.025***	-0.024***	-0.025***	-0.025***	-0.025***	-0.025***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Fibre-young	0.462***	0.463***	0.461***	0.461***	0.461***	0.461***
	(0.039)	(0.038)	(0.038)	(0.038)	(0.038)	(0.038)
Fibre*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)
Fibre*distance-young	-0.099***	-0.101***	-0.101***	-0.101***	-0.101***	-0.101***
	(0.024)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Observations	11,987	11,998	12067.00	12,067	12,067	12,067
Cragg-Donald F	18.60	18.89	19.32	19.07	19.07	19.07
Kleibergen-Paap F	10.84	11.29	11.45	11.40	11.40	11.40
J-stat (p-value)	0.43	0.43	0.01	0.18	0.42	0.24

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Table A3: Impact of cloud Table 12 Impact of cloud on firm growth: incumbents, small and large young firms

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Log Employment	Labour productivity	Multi plant	Log No. Plants	Log No .Plant Deaths	Log No. Plant Births
Specification	IV		IV	IV	IV	IV
Cloud -incumbent	0.444	-0.122	-0.001	0.176	0.612***	0.231
	(0.308)	(0.359)	(0.122)	(0.110)	(0.208)	(0.223)
Cloud-young-small	1.327***	0.298	-0.363**	0.006	0.040	-0.035
	(0.387)	(0.442)	(0.143)	(0.125)	(0.213)	(0.235)
Cloud-young-large	-2.247***	0.501	0.271**	-0.170	-0.112	-0.833***
	(0.308)	(0.393)	(0.131)	(0.182)	(0.198)	(0.296)
Observations	12554.00	12561.00	12614.00	12614.00	12614.00	12614.00
Cragg-Donald F	12.03	11.99	12.16	12.16	12.16	12.16
Kleibergen-Paap F	7.35	7.37	7.48	7.47	7.47	7.47
J-stat(p-value)	0.17	0.77	0.16	0.11	0.47	0.62

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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.*

Table A4 Impact of cloud on geographic dispersion – incumbents only

	(1)	(2)	(3)	(4)	(5)
Dependent variable	Average distance (weighted)	Average distance	Covariance	No. Local authorities	Herfindahl index
Specification		IV	IV	IV	
Cloud -incumbent	26.528*	12.939	13.589	0.179	-0.021
	(15.934)	(17.322)	(13.947)	(0.150)	(0.052)
First stage Cloud- Incumbent					
Fibre -incumbent	0.101***	0.101***	0.101***	0.101***	0.101***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Fibre*distance-incumbent	-0.023***	-0.023***	-0.023***	-0.023***	-0.023***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Observations	11467.00	11467.00	11467.00	11488.00	11488.00
Cragg-Donald F	17.58	17.58	17.58	17.74	17.74
Kleibergen-Paap F	9.97	9.97	9.97	10.06	10.06
J-stat (p-value)	0.99	0.42	0.27	0.88	0.20

*Notes: All regressions include year and firm fixed effects and firm controls of a multi-plant 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 plants from their headquarters, where the weights are the share of plant employment in firm employment. The covariance term measures the correlation between plant employment and distance from the headquarters, i.e. whether further plants are larger (a positive covariance), or closer plants are larger (a negative covariance) in terms of employment*.