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The Effects of the Digital Transformation on the Workplace and the Labor Market

ICT and Capital Saving Technical Change

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ICT AND CAPITAL SAVING TECHNICAL CHANGE

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Abstract

Historical analysis of past general purpose technologies has suggested that multi-factor productivity gains are realised through both labour saving and through capital saving features of these technologies. In this paper, we explore for the first time whether ICT leads to capital saving, generated by squeezing a greater amount of economic activity into a smaller amount of space. To do so we use new regional data on building capital for the UK and cross-space and time variation in broadband connection speeds. We find evidence of capital biased technical change that is robust to wide-ranging tests for robustness, falsification and endogeneity bias. The capital biased technical change effects of ICT provide a new perspective on the recent discussion about the 'death of the high street' and, as this type of capital is typically assumed to be constant, likely represents an aspect of TFP missing from estimates constructed at both the micro and macro level.

Keywords: ICT; technical change; general purpose technology

JEL codes: E22; L23; O4; R3

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1. Introduction

General purpose technologies (GPTs) are characterised by the wide ranging economic transformations they make, including to the range of goods and services that are produced, the type of production tasks that are undertaken and the way they are organised, the skills that are valued and where production is located. This impacts the growth and level of income through increases in multi-factor productivity as a consequence of both labour and capital saving features of the technology (David, 1990, 1991; David and Wright, 1999, 2003).

The capital saving effects of GPTs are thought to appear slowly over time, and consequently, have been much less commonly studied. A well-known example of capital savings from a historic GPT, electricity, is described by Devine (1983) and David (1990, 1991). They document how, 40 years after Edison's invention of the carbon filament incandescent lamp in 1879, electrification led to a transformation from group drive to unit drive transmission within manufacturing. This in turn affected the efficiency with which the space in factories was used and began to alter their design, favouring single-story structures with a larger footprint that allowed the free-flow of inputs throughout the plant. These slowly made changes to the shape, layout and the materials used to construct factories reduced the capital requirement of firms, generating multi-factor productivity gains that across the economy as whole, took many decades to complete.[1]

In this paper, we explore whether a modern general purpose technology – information and communication technologies (ICT) – shares this same capital saving feature.[2] Motivation for this analysis comes from David and Wright (2005), who draw on the historical analogy of the introduction of portable power to discuss the ways that ICT has changed work practices, including for example open-plan offices, working from home and hot-desking.[3] The use of ICTs such as Virtual Private Networks, and the speed and reliability of internet connections could, they conjecture, "yield significant capital-savings in the reduced requirement for commercial office space". Further effects may come from increased flexibility to the hours and pattern of work including in locations away from the office. A primary motivation for these ICT-enabled flexible working approaches therefore appears to be to reduce building

[1] Capital saving is not confined to electricity as a GPT. Acemoglu (2003) writes, while it seems plausible to think of many of the major inventions of the twentieth century, including electricity, new chemicals and plastics, entertainment, and computers, as expanding the set of tasks that labor can perform and the types of goods that labor can produce. Field (1987) writes specifically about the capital saving effects of management and its spread following the invention of the railways. In contrast, some of the early important technological improvements, such as the introduction of coke, the hot blast, and the Bessemer process, can be viewed as capital-augmenting advances, since they reduced the costs of capital and other nonlabor inputs.

[2] Whether ICT qualifies as a GPT was originally the subject of some considerable debate, but has now been accepted by many (David, 1990; Bresnahan and Trajtenberg, 1995; David and Wright, 2005; Jovanovic and Rousseau, 2005) if not all (Gordon, 2000, Field, 2006).

[3] Gaining precise statistics on the extent of the use of these types of work practices is difficult. A 2016 study by the UK property company Savills suggests that 73% of UK office workers do so in an open-plan office

space and save on office costs (Bennett, 2016).[4] More recent technological changes within ICT may have further accelerated this process. Cloud computing and superfast broadband have allowed for a greater decoupling of the production, storage, processing and application of information, offering firms' cost motives to reorganise or relocate production activity. It has also saved on the space necessary to house servers etc. In the last few years, it has even led to the growth of a new type of business that allows shared office space to be hired in a way that transforms the costs of building capital from a fixed to a variable cost.[5] In summary, there are good reasons to suspect that ICT is capital biased, although there are no estimates of how important his has been. Secondly, the way ICT is capital saving – allowing more workers to be squeezed into the same space – contrasts with the effects of electricity on the construction of factories.

This paper provides the first empirical evidence for this type of capital saving by exploiting new data for the UK on building capital, measuring by the area of business properties (its metres^2) and intensity with which the capital is used (the average size of business properties and the space, m^2, per employee). From this data we construct a long-difference regression, which captures the effects on building capital for a 12-year period during which internet speeds grew rapidly. For identification, we exploit the fact that these speeds have increased to varying extents across the UK, increasing from 256kbps to an average of over 15mbps but with a range of between 4 and 24mbps, generating time and cross-sectional variation. We use this to answer two principal questions: was ICT associated with changes in the use of building capital? And, if so, how large is the effect?

The main threat to identification comes from the fact that the internet connection speeds within a local area are affected by historical and geographic factors that may similarly affect their suitability as locations for commerce. For example, London has been a centre of commerce for several millennia and more recently has received significant investment in the infrastructure to deliver broadband internet. The removal of these time invariant regional factors differencing across time underpins our use of a long difference strategy. A second potential concern is the presence of time-varying, region-specific economic factors, in particular given that our time period includes the global financial crisis in 2007/8 and the fiscal austerity programme started in 2010. To control for such effects we use time-varying measures of local economic activity such as the unemployment rate and allow for permanent

[4] It would seem likely that these changes in office lay-outs have also affected the productivity of workers, although the evidence from this literature is rather mixed (Haynes, 2008). Unfortunately the data that are available to us do not allow us to identify which offices are using particular work-practices and therefore to provide evidence on this point.

[5] One UK based company reported in 2018 the fixed versus hot-desk prices in a range of locations within London. On average, the hot-desk rate was around two-thirds of the fixed desk rate. This is close to the 30% reduction used as a benchmark in the industry.

differences in the growth rate of building capital that are associated with initial conditions, such as income and the size of the agglomeration measured by population.

A remaining issue is the presence of unobservable region specific changes that may confound our results. We might think of two main types of local factors that vary in this way. Firstly, the time period that we study also coincides with a general increase in the popularity of living within the city-centre, in part due to the attraction of fast internet speeds. This increase in new residential properties has affected the competition for land within the city-centre, affecting prices and therefore possibly encouraging some firms to relocate. The increase in the popularity for city-centre living is likely to vary across cities according to, unobservable to us, city-centre amenities and the attractiveness of the centre. The positive correlation between the popularity of residential city-dwelling with internet speeds, and the negative correlation with land prices and therefore building capital would indicate that our estimates are likely biased in a positive direction even after first-differencing. Second, the UK has no national planning laws (Cheshire, 2018). Decisions are instead made by local political committees that are affected by local political changes across time, lobbying and political expediency. This is likely to bias outcomes in an unknown direction. To confront these points, we develop an instrumental variable approach that exploits the fact that the infrastructure through which the most commonly used types of internet are delivered, depends on the legacy of the telephone network. This generates plausibly exogenous spatial variation in the connection speeds available across regions.

The data allow for a comparison of the effects of ICT on business properties used as offices with those used for retail and industrial purposes. An open question is whether the building capital savings discussed by economic historians for office space are also apparent for buildings used for these other functions. The sector most obviously affected by the growth of the internet has been the retail sector, with the traditional ‘bricks-and-mortar’ retailers facing an increase in competition from those using e-commerce exclusively or as a hybrid of these. Hortaçsu and Syverson (2015) detail how retail has been affected by the expansion of warehouses and supercentres as a consequence of e-commerce, which may suggest a similar fall in the footprint. But, ICT has also acted to reduce the number of employees that are required, such that the footprint of the firm per employee may have actually risen. We provide an answer to what is ultimately an empirical question.

The industrial sector, in contrast, might be expected to behave more similarly to office space. Here the increased use of ‘just-in-time’ technologies have reduced the need for warehousing, while the offshoring of production has reduced the space needed for machinery as part of production. At the same time, many manufacturing firms have become more service intensive, which typically requires less space. The net effect of these various trends is likely faster falls in the use of space devoted to this sector compared to employment, such that the overall intensity with which space is used increases.

Our main finding is that ICT also leads to capital saving technical change, by reducing the building capital requirements. Locations with faster broadband connections speeds have been subject to the largest decrease in building capital, where this effect is economically significant. For every increase in broadband speeds of 1mbps, the m^2 area available for commercial rent falls by 0.7%. Therefore, it seems the productivity gains commonly found in the literature from ICT, are in part due to allowing greater economic activity to be squeezed into a smaller amount of space. Moreover the effect is economically important. Given the rapid increase in broadband speeds across the sample period this equates to a reduction of 10.5% in this measure of building capital by 2012. To put this figure in perspective, without this increase in broadband speeds an additional 41 million m^2 of building capital (compared to a total of 433 million m^2 in 2012) would have been required in the UK over this 12 year period, which is equivalent to over 60% of the total commercial floorspace in London in the year 2000.

This result is robust to considerations of endogeneity bias explained by time invariant regional characteristics and to controlling for observable regional characteristics along with those correlated with initial conditions. The results are also robust to the use of an instrumental variable approach exploiting exogenous regional variation in the telephone network on which most broadband internet connections rely. We also find evidence that this type of capital biased technical change has mattered more in industries reliant on office and industrial buildings as opposed to those in retail sectors. To further build the case for a causal interpretation we test whether our results are driven by unobservable region specific shocks and apply a falsification test using the average size of residential properties. The shape of residential properties should be unaffected by changes in ICT in the same way as commercial property. For residential properties we find that the effect of broadband has been to *increase* the average size, although the magnitude of the effect is very small. Altogether, these robustness tests suggest that a conclusion of a causal effect from ICT on building capital is possible.

As a final exercise we examine the implications of our results for the geography of economic activity. Here we draw a second analogy with past GPTs. Prior to the development of electricity and unit drive motors manufacturing firms were tethered to rivers as a source of power. Their invention allowed firms a greater freedom in location choices, in principle spreading economic activity. At first glance, recent ICT invention similarly allows greater mobility by lowering the costs of information transmission, a view supported by empirical evidence by Kolko (2012), Ioannides et al. (2007) and Sivitanidou (1997). However, the infrastructure of the internet constrains the location of economic activity reliant on these internet based technologies just as steam-powered engines were limited by the location of rivers. As internet speeds have typically grown most quickly in cities in the UK, this would indicate that the capital biased effects of ICT we study have acted as a force towards increased agglomeration.

Our explorative investigations of this point suggest that faster internet speeds are negatively correlated with these measures of economic size, confirming previous evidence that faster communication speeds act to disperse economic activity. In the same regressions we also find that building capital (m^2) per employee is significantly negatively correlated with economic mass, indicating that falls in the amount of space per employee does indeed increase the scale of economic activity that occurs in a region. As far as we are aware, this link between capital saving and economic geography has not previously been explored in the literature.

The paper continues as follows: Section 2, provides a review of the related literature on capital biased technical change and the broader effects of ICT. Section 3, outlines the empirical strategy. Section 4, discusses the data used, along with an explanation regarding the key establishment and broadband variables followed by some descriptive statistics. Next, Section 5 presents the empirical results, while Section 6 provides various tests for robustness. In Section 7 we explore the economic geography effects of ICT and in Section 8 we draw some conclusions.

2. Related Literature

The existing empirical and theoretical evidence on capital biased technical change is somewhat scattered across several strands of the literature. To understand the macroeconomic effects of capital augmenting technical change a natural reference point are theories of economic growth. Here the idea of capital augmenting technical change has been viewed as relatively unimportant. Such models have at their centre the stylised facts of Kaldor and in particular, the relative constancy of factor shares, usually known as the balanced growth path. As discussed by Acemoglu (2003), almost all growth models generate predictions consistent with this balanced growth path by assuming that the elasticity of substitution between capital and labour is equal to be one, or by restricting all technical change to be labour augmenting. While factor shares display a broad constancy over time in countries such as the US and UK, they also contain obvious periods, sometimes lasting for several decades, in which these ratios are not constant (Acemoglu, 2003; Pikety, 2014; De Loecker and Eeckhout, 2017).

Acemoglu (2003) models these departures from the balanced growth path by allowing for capital augmenting technical change. He shows that as long as the elasticity of substitution between capital and labour is less than 1, the balanced growth path contains only labour-augmenting technical change. Capital augmenting technical change acts to increase the labour share of income in the model. This would suggest that the recent gains to capital are not universal across its different forms. More recently Grossman, Helpman, Oberfield and Sampson (2017) develop a model with human capital accumulation and capital-augmenting technical change that retains a balanced growth path. A further example can be found in Jones (2005) and more recently in Irmen (2017).

Standard version of these two-factor models of aggregate production would suggest that capital saving technical change should be associated with a declining share of capital in income (Barkai, 2016; Barkai and Benzell, 2018) and therefore act a countervailing effect on the recent falls in the labour share of income found empirically for many countries (Karabarbounis and Neiman, 2013). Recent work by Barkai (2016) and Brkai and Benzell (2018) has shown that the income share paid to capital has also fallen across time however. As Benzell and Brynjolfsson (2019) recognise, these models offer little to explain why both the labour and capital share of income may simultaneously decline, given the evidence that digital technologies have both capital and labour saving features. To generate such predictions they introduce a new input, labelled 'genius', which is complementary to technological change.

This paper also has a connection with the literature on the production function and estimating rates of capital and labour augmenting technical change at the country level, typically using some form of time trend as a proxy, and for an aggregate capital stock measure. The earliest example of this is Sato (1970) who derives factor biased technical change within the production function and discusses its relationship with the elasticity of substitution and factor labour shares. He uses data on the US non-farm economy from 1909 to 1960 to estimate the rates of capital and labour augmenting technical change. He finds that technical progress is on the average labour-saving, growing at a rate about 1/3rd higher than capital-saving technical change. Evidence of capital saving technical progress for the aggregate capital stock is not a ubiquitous outcome in this literature, motivating the focus on a particular form of capital used in this paper. For example, Berman (2000) finds evidence using cross-country and industry level data of absolute capital bias from technical change. Antras (2004) finds similar evidence of capital-using for the aggregate capital stock.

Our focus on capital augmenting technical change contrasts with the voluminous literature examining the more general productivity impacts from ICT. It has become broadly accepted in this literature that ICT use leads to increased productivity growth, see for example Brynjolfson and Hitt (1996, 2003); Dewan and Min (1997), Black and Lynch (2001, 2004), Bloom et al. (2005, 2014). There is also evidence these technologies have had strong effects on workers displaying a strong positive bias towards higher skill workers and away from lower skilled workers (Akerman et al., 2015). Within this literature there are a small number of papers that have previously examined ICT and capital saving, albeit for a different form of capital. Hubbard (2003) provides one example. He finds evidence that the use of on board computers affected capacity utilisation in the trucking industry.[6] According to his estimates about 33 percent of the 10.1% increase in loaded miles per truck between 1992 and 1997 was related to the growing use of on-board computers to achieve better matches between trucks and hauls. An alternative type of ICT is explored by Cramer and Kreuger (2016), who study the capacity utilisation of UberX drivers versus those employed by traditional taxi cab firms. They find that capacity utilisation is higher amongst Uber drivers, which is in part determined by the technology that Uber has developed to match drivers and passengers.

Change in the use of space would indicate that this paper also fits with the literature on organisational capital and ICT.[7] A commonly held view in this literature is that the productivity effects of ICT are increasing in organisational capital, but also that the costs associated with changes in organisation can be substantial. Yang and Brynjolffson (2001) for example report evidence that the total start-up cost of some types of ICT are five times the cost of the hardware and software licences.

While it is evident from the discussion of the effects of previous GPTs from Devine (1983) and David (1990, 1991), as well as those of ICT in David and Wright (2005) that capital saving technical change often occurs alongside other organisational changes, it is clear that the mapping between these two concepts is imperfect. Organisational changes may or may

[6] Hubbard (2003) does not himself make the link to capital augmenting technical change.

[7] Simple correlations between measures of ICT and productivity are typically larger than those suggested by growth accounting. The explanation that the high magnitudes are due to organizational capital gets some support from Bresnahan, Brynjolfsson, and Hitt (2002) who conducted a survey containing explicit questions on decentralization within firms. Bloom, Sadun, and Van Reenen (2005) find some support for the organizational capital hypothesis as they find much higher returns for the IT in US multinationals compared to non-multinationals than between statistically similar establishments in the UK. Black and Lynch (2001) also find a positive correlation between ICT use and workplace organisation, as do Crespi et al. (2007). Bertschek and Kaiser (2004) find no such relationship.

not bring about capital saving changes. The possibility that organisational change from ICT might bring about capital saving is ignored in the existing literature, where building capital is often missing from estimates of the total capital stock, or is assumed it to be constant. This suggests that estimates of TFP from the organisational changes brought about by ICT are likely to be under-estimated. Instead the literature has focused on types of organisational changes, such as management hierarchies, that can be more easily quantified.[8]

Finally, as this paper studies how the available space is used in the production of economic activity, it is related to a small literature on the economic geography effects of ICT. A well known study by Kolko (2012) finds a positive relationship between broadband expansion and economic growth in cities, especially in areas with lower population densities. This might be viewed as consistent with the evidence form this paper.

Ioannides et al. (2007) take a very different approach to this question, testing directly whether the distribution of the size of cities have become more or less similar over time. They reach the opposite conclusion that ICT leads to a less concentrated distribution of city sizes, suggesting that it acts to disperse economic activity across geography.[2] 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. We find the opposite for a more recent ICT. As already mentioned we return to this point in the last empirical section of the paper.

3. Empirical Strategy

The empirical model that we wish to estimate takes the following form:

$$y_{it} = \alpha + \beta X_{it} - \gamma ICT_{it} + \varepsilon_{it}$$

Where *y* is one of our measures of business capital such as the area (m^2), the average size of each hereditament, or area per employee in region *i* at time period *t* (2000 or 2012); ICT is the broadband connection speed within the region and *X* includes a series of control variables. If ICT is indeed capital biased with respect to building capital then the estimated coefficient γ is expected to be negative. Within *X* we include measures of the price of building capital (the rateable value in m^2), and the level of output, such that the regression resembles that of a standard factor demand equation. An equation of this type can be

[8] Fabling and Grimes (2016) note that shifts in production towards more ICT-intensive products, while research on the relationship between organisational change and skills include Carolli and Van Reenen (2001, Akerman et al. (2012).

derived from the neoclassical model of Jorgenson (1963) in which firms maximise the discounted flow of profits over an infinite horizon with delivery lags and adjustment costs. The literature on estimating factor demand equations for capital is summarised in Chrinko (1993).

A concern with the estimation of the above model is that any naïve estimates of the coefficient on ICT are likely to be biased due to the presence of time invariant confounding factors at the regional level. For example, regions in which there are large agglomerations of businesses are also likely to be large agglomerations of workers and therefore customers for internet technologies. To remove the influence of these time invariant regional characteristics we estimate equation (1) in long difference form, such that we now capture the change in business capital over the 12 year period from 2000 to 2012. A long difference approach of this type is adopted by Brynjolffson and Hitt (2003) when considering the productivity effects of ICT. In the base year broadband were constrained by the limits of the copper cabling that make up the telephone network and therefore limited to 256k.b.p.s. The first generation of ADSL broadband only became available to purchase in that year. For this reason, instead of the change in connection speeds, we use the speed available at the end of the sample period.

4. Data and Summary Statistics

Our measures on the number and size of business properties is from the UK Valuation Office Agency (VOA) administrative database. This newly available dataset provides time series data on the numbers of hereditaments[9], total rateable values, total area of floorspace (thousands m^2) and average rateable values per meter squared for local authorities in England and Wales from 2000 to 2012. A hereditament in the data is a property on which rates, a local property tax in the UK, may be charged. In general hereditaments are buildings, or premises within buildings, appropriate or used for single occupation. The floorspace is measured in (thousands) square metres and includes all of the commercial space. Therefore businesses properties spread across multiple floors have a larger floorspace in our data than a single story business property which has the same land footprint. We combine the data on total area and total hereditaments to calculate area (m^2) per hereditament.

Hereditaments in the data include those that are either occupied or vacant, and therefore differ from data about the birth or death of firms. If a firm death occurs and a new one is born

[9] A hereditament is defined in the UK according to the answer to the following question: "as a matter of fact and degree, is or will the building, as a building, be ready for occupation, or capable of occupation, for the purposes for which it is intended?" VOA

into the same property this does not show up in the data. Reductions in the number of hereditaments and their floorspace therefore represent newly built properties, the demolition of a business property or a change in its use, for example an industrial property reconfigured for housing or into retail units. The vacancy of a property also has no impact on rateable value, though it can affect the level of rates levied on a property. The rateable value of property is the value at which a property might be expected to be let for one year. It is based on a range of factors including use, location and age, but a major determinant of rental value is the size (total area) of the property. For many of the more common types of commercial properties, the VOA allows separation by type of property including those used as retail properties, offices, factories and warehouses and a small miscellaneous group which consists mainly of halls, social clubs and garden centres.

Information employment at the local authority level comes from aggregating information held within the Business Structural Dataset (BSD). The BSD is generated from the *Inter-Departmental Business Register* (IDBR), which is a live register of data collected by HM Revenue and Customs via VAT and Pay As You Earn (PAYE) records. This dataset contains basic information for almost every firm organization in the UK. Estimations in 2004 for example suggest that the businesses contained in the IDBR represent roughly 99% of all business activity in the country. From this dataset we use information on the precise location of the firm to match this to a local authority and then aggregate across firms. To match types of commercial properties to employment we match descriptions of the types of commercial properties in the VOA with SIC codes. To measure the level of output we use information from the ARDx for 2000 and 2012. We measure output using the location of the local unit of the firm. We combine the data on total area with the employment data to calculate the area (m^2) per employee within a local authority.

The data on broadband speed come from the Office of Communication (Ofcom), the regulatory authority for the communication industry in the UK. These are available at the postcode level for 2013.[10] We then aggregate this data to the local authority level to match that from the VOA.

The data on business premises indicate there were around 1.53 million commercial properties in England and Wales in 2000. By 2012 this had grown by over 11% to 1.63 million. Across each local authority this meant an average of 1,106 business premises, rising to 1,228 by 2012. This rise in the number of hereditaments was matched by growth in employment, such that the average m^2 per employee fell slightly.

[10] Broadband speed data are not available from OFCOM before 2013. For this reason we are unable to estimate a panel regression model.

Summary statistics are displayed in Table 1, where we report means and standard deviations for total area (thousands m^2), the number of business properties (hereditaments), employment, the average size of each business property and the area per employee for the years 2000 and 2012. We report these for all types of properties along and for office, retail and industry categories separately.

The average space per hereditament in 2000 was similar in office and retail (258m^2 and 192m^2) than in the industrial sector (715m^2). The average area per employee also differs noticeably across these three categories, with much less space per employee (around 20m^2) for office workers compared to those in retail (635m^2) and industry (181m^2). It is difficult to find accepted industry standards against which to compare these data, although for office the usual range quoted for the UK is between 14m^2 and 32m^2 per employee. Our data appear to conform to these generally accepted rules.

In the average local authority there was an increase in the number of business properties in the UK, along with the total area and employment across the 12 years between 2000 and 2012. This growth mostly accounted for by growth in office space, where there was a marked increase in the number of office units (34%) and in the floor area within each local authority (17%). For retail and industrial units there are some interesting differences. The number of retail properties fell by 2.5%, but total space grew by 7.6%, whereas there were declines for both the number (0.4%) and the space available in industrial units (2.8%). This led to declines in the average size of each hereditament overall, and in office and industrial units, but growth in the average size of retail units. Measured in terms of space per employee there is evidence of an overall decline, made up of reduced space per worker in office and retail units and an increase in industrial units. The decline in space per employee is particularly noticeable in the retail sector.

We provide further stylised facts about the number and floors area contained within business properties in the UK across Figures 1 to 4. In each diagram we plot the value in 2000 against that in 2012 for the three types of business property. Points above the 45º line local authorities in which there has been growth in the variable and points below regions in which there has been a decline. A first obvious feature of the data is the strong persistence in commercial space within a region. Even across a 12 year period the regions with large amounts of business properties in 2000 were the same regions with large volumes of business properties in 2012. The figure also shows that, typically there are more office properties that retail and industrial properties.

Across time the data also reveal there has been general growth in the number of business properties, in particular in regions with an initially smaller number of industrial properties.

Figure 3 would tend to suggest that this is not simply due to the division of larger industrial units as the total space also rises.

For the measures of the average size of each hereditament and the intensity with which employment is cramped within it, there is both obvious heterogeneity across regions and across types of property. It is evident that the average size of office units are larger than those for industries, which in turn are larger than retail units. However, retail units typically have fewer workers per m^2, and industrial units the most. It is also evident from these figures that there is noticeable variation across regions as to whether the average size and floorspace per employee rose or fell over time.

Table 1: Summary Statistics

	Year		Commercial Area (thousands m^2)	Hereditaments	Employment	Area per hereditament	Area per employee	Obs
All	2000	Mean	848.6	2106.1	16401.5	388	279	1146
		Std. Dev.	2202.9	4531.8	26516.6	288	2247	
	2012	Mean	868.6	2227.1	16772.0	380	240	1146
		Std. Dev.	2139.2	4664.5	29671.7	286	1958	
Office	2000	Mean	384.4	1300.5	30467.7	258	20	382
		Std. Dev.	1136.5	3241.5	38733.1	104	70	
	2012	Mean	450.0	1742.7	35820.7	225	19	382
		Std. Dev.	1312.6	4208.7	44369.2	85	57	
Retail	2000	Mean	528.7	2805.4	1474.8	192	635	382
		Std. Dev.	1032.7	5688.8	1258.8	46	3710	
	2012	Mean	569.0	2734.9	2120.6	214	498	382
		Std. Dev.	1086.4	5551.9	1492.2	53	3256	
Industry	2000	Mean	1632.8	2212.3	17261.9	715	181	382
		Std. Dev.	3360.2	4207.0	13737.7	270	1097	
	2012	Mean	1586.7	2203.5	12374.6	702	202	382
		Std Dev.	3172.9	4044.2	8751.0	283	891	

Notes: Data Sources: Floorspace, Hereditaments and Floorspace per hereditament are from UK Valuation Office and are measured at the local authority level. Employment is from the Business Structure Database from the ONS and is aggregated to the local authority level. We report the mean and standard deviation.

Figure 1: Number of hereditaments within a local authority by type of hereditament, 2000 and 2012

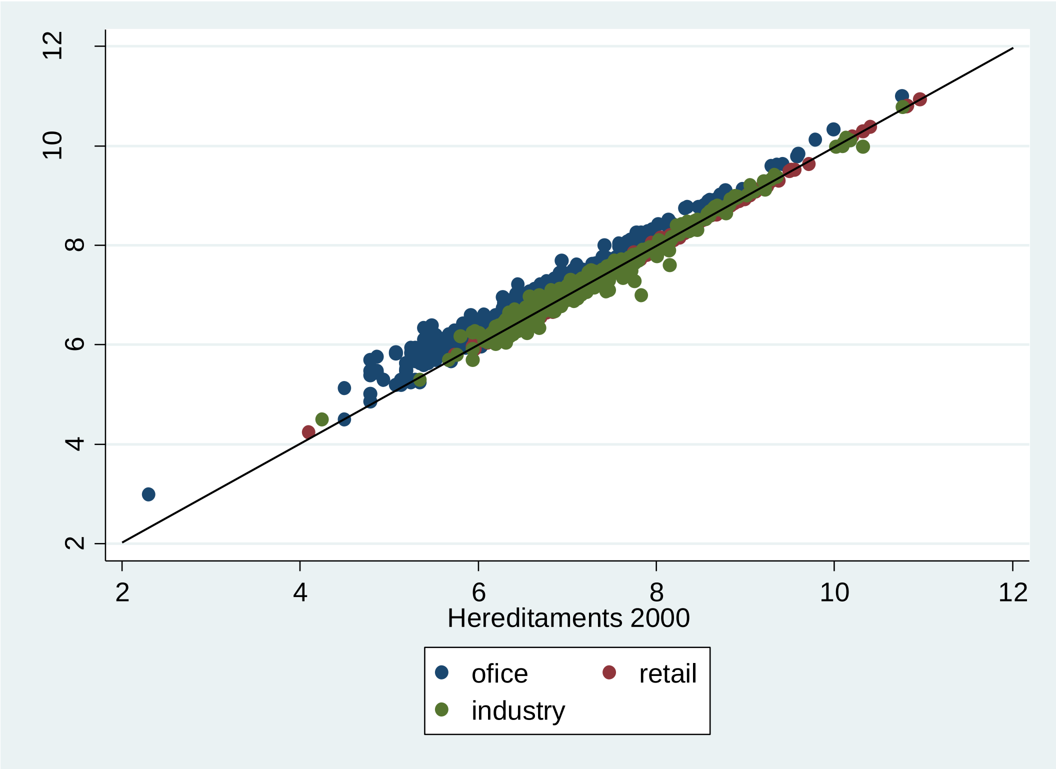


Figure 2: Total commercial Space within a local authority by type of hereditament, 2000 and 2012

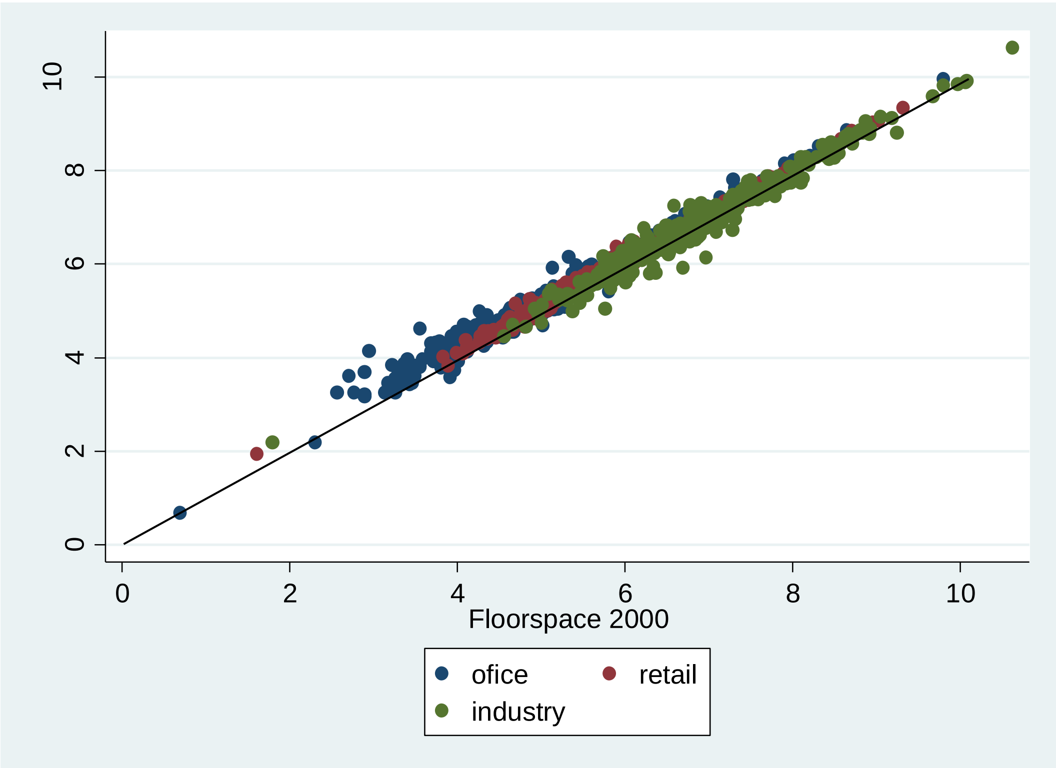


Figure 3: Area per hereditament within a local authority by type of hereditament, 2000 and 2012

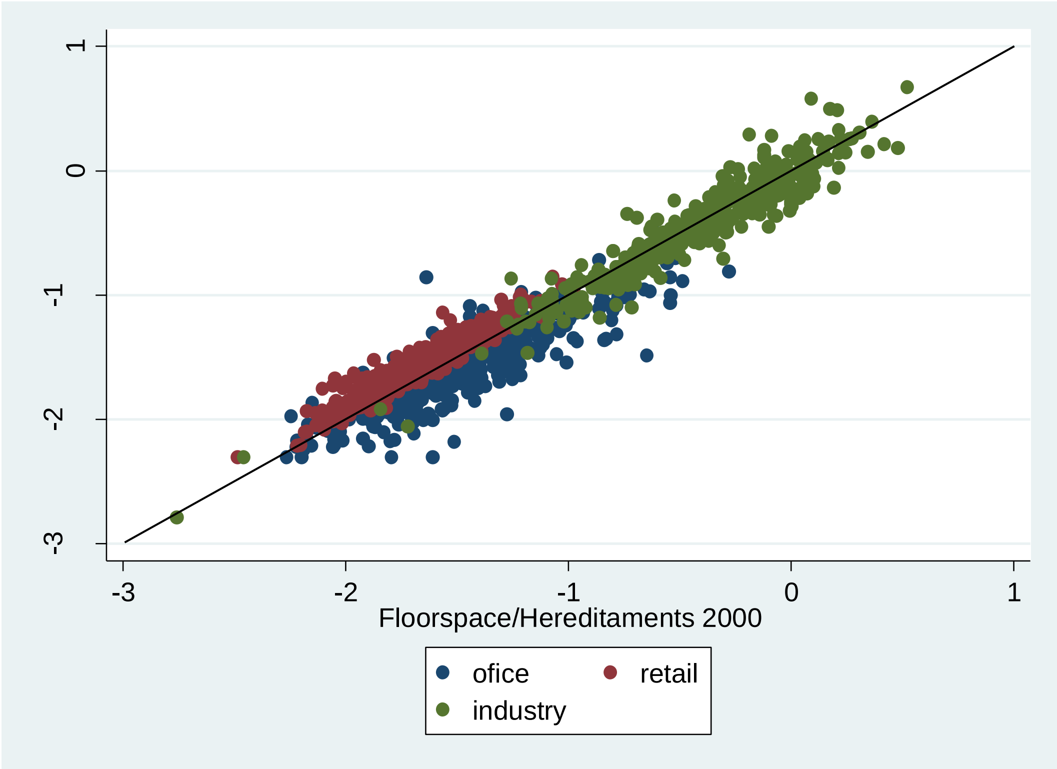
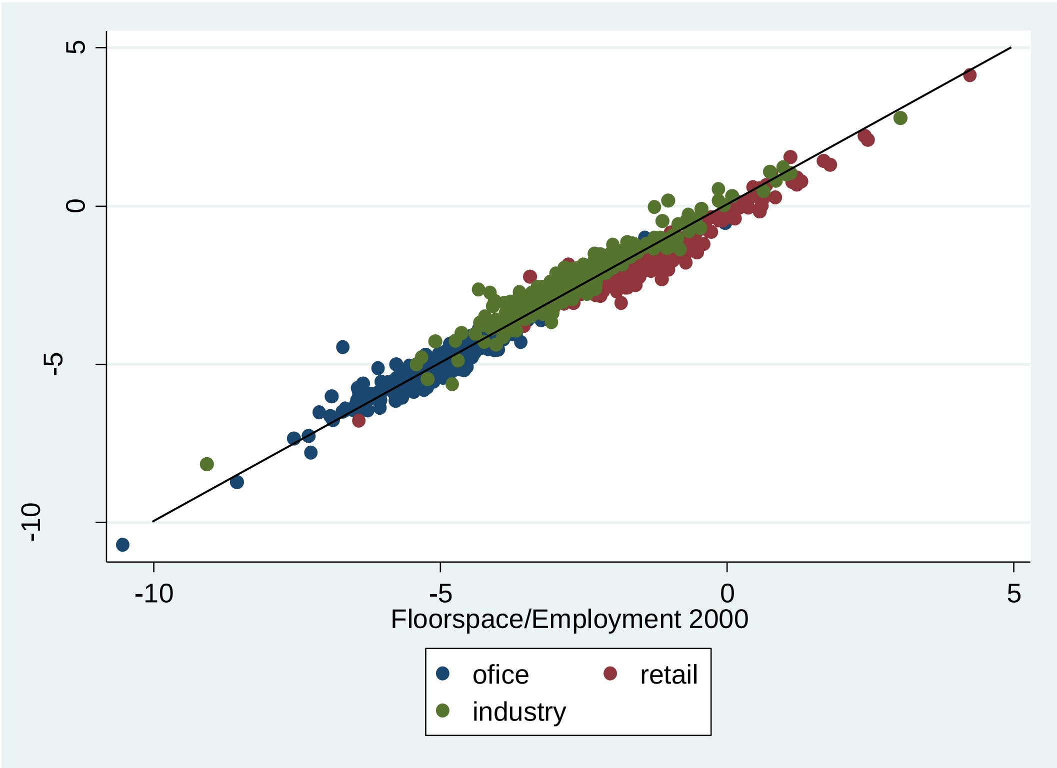
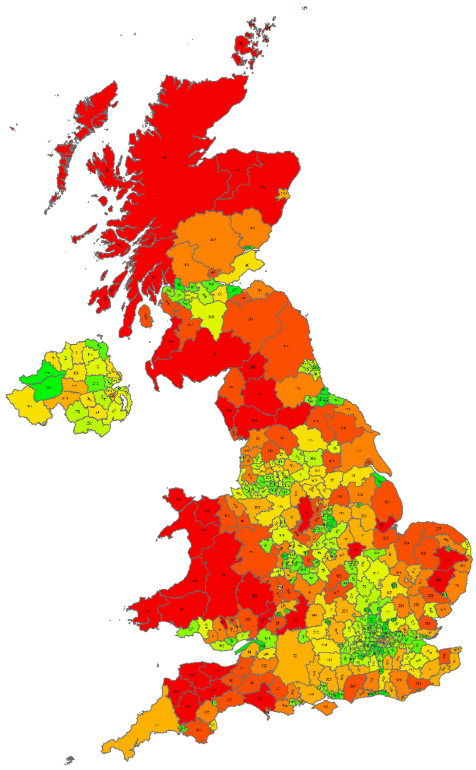


Figure 4: Area per employee within a local authority by type of hereditament, 2000 and 2012



In Figure 5 we plot the average speed of broadband connections in each local authority. The figure shows that the highest speeds are available in the large conurbations of the UK. These speeds become slower as the distance from the largest conurbations of London, Birmingham and Manchester increase. The slowest broadband speeds are in rural locations in the South West, Mid- and North Wales, the North West of England and Northern Scotland.

Figure 5 Broadband connection speed by local authority



5. Regression Results

In Table 2 we estimate a factor demand equation that controls for the broadband speed alongside the level of output and the price of capital. In regression 1 we consider how the demand for floorspace depends on the level of output, the price of capital and broadband speed using data for 2012. As expected we find a strong positive relationship between the available commercial space and output and a negative correlation with prices. We also find that regions with faster broadband speed tend to have larger building capital stocks measured by area.

There are strong reasons to suspect that estimated coefficient on broadband speed in regression 1 is unlikely to capture the causal effect of ICT on building capital owing to omitted variable bias. Business properties and consumers are agglomerated in cities, which are also locations in which the volume of demand for broadband services are highest. Cities therefore tend to attract greater broadband investment and therefore have faster broadband speeds on average. The omission of the necessary control variables such as agglomeration from this regression will therefore tend to strongly bias the effect of ICT on capital in a positive direction.

Our first approach to this issue assumes that these problem confounders are location specific but time invariant. To remove the effect of these regional characteristics, in regression 2 we first difference the data across time. To allow for the possibility that building capital changes take a long time to appear we difference the data from 2000 to 2012, creating a cross section of long-differenced data. The relationship between the total floor area and broadband differs markedly when we account for time invariant regional characteristics in this way. The estimated broadband coefficient switches and is now negative, consistent with an interpretation of capital biased technical change from ICT on building capital.[11] According to these estimates for every increase in broadband speeds by 1 mbps, business capital fell by 1.1%.

First differencing helps to remove the effect that broadband speed may have on business capital because these speeds are also correlated by time invariant characteristics of a local authority, such as geographic or historical characteristics that make a particular location a more or less attractive place to site a business. In regression 3 to 9 we consider further the robustness of the results to this issue and in particular that any omitted variables also affect the growth of building capital in a region.

Large agglomerations have larger numbers of business properties as well as larger populations and therefore employment. To remove the possible effect of the size of agglomeration on the growth in building capital over time in regression 3 we add to the regression the change in hereditaments, while in regression 4 we control for the initial value of the commercial space in the region. This latter variable is motivated by evidence from Figure 1, which showed the growth in the number of hereditaments across time was concentrated in regions with initially lower stocks of business properties. It has also been used in the literature on capital investment equations to account for adjustment costs (Chrinko, 1993)

[11] This result for broadband speed is robust to the inclusion of non-ICT capital stock to control possible complementarities with floorspace. The result is also robust to the inclusion of the initial price of capital to control for the possibility that broadband and changes to business properties are correlated with initial prices and these affect the rate of change of these variables across time.

Table 2: Baseline regression results

Regression No. *Dependent variable*	**1** **Area (m^2)**	**2** **Δarea (m^2)**	**3** **Δarea (m^2)**	**4** **Δarea (m^2)**
Broadband speed	0.072***	-0.011***	-0.007***	-0.006***
	(0.010)	(0.001)	(0.001)	(0.001)
Output	0.204***			
	(0.046)			
Price of Capital	-0.549***			
	(0.057)			
ΔOutput		0.022***	0.021***	0.009
		(0.007)	(0.005)	(0.007)
ΔPrice of capital		0.018	0.151***	-0.013
		(0.036)	(0.035)	(0.034)
ΔHereditament			0.584***	
			(0.031)	
$Floorspace_{t-1}$				-0.071***
				(0.006)
R^2	0.272	0.084	0.457	0.234
Observations	1026	1026	1026	1026

Notes: Regression for the change in the area (m^2) of commercial properties between 2000 and 2012 within a UK local authority by type (office, retail and industrial).

In regressions 5 we take an alternative approach and scale the commercial space variable by the number of hereditaments within a region to construct a measure of the average m^2 per hereditament. In regression 6 we scale total area by employment to construct a measure of m^2 per employee. If any omitted region characteristics are correlated with the number of businesses in a region then scaling to use m^2 per hereditament or m^2 per employee will remove such effects. To reflect the change in the left hand side variable, m^2 per employee, in regression 5 we use also divide output by the number of hereditaments (capital productivity) and in regression 6 we divide output by employment levels (labour productivity).

In regression 7 we extend this idea and allow for the possibility that changes in building capital are more closely related to changes in employment rather than output. That is we use the same specification as regression 2, but with the change in employment rather than output as a control variable. A further advantage of adding the change in employment to the regression is that this then controls for any effect from ICT on labour augmenting technical change.[12]

[12] We report estimates of labour augmenting technical change in Table A1. The evidence presented in Table A1 points to such a conclusion, irrespective of whether we estimate using OLS or use an instrumental variable approach. The results yield coefficient estimates on the broadband variable that are around half that of the equivalents for building capital. Unfortunately the ONS data do not allow use to separate employment into different types of skills and therefore to consider issues about skill biased technical change.

In regression 8 we take a different approach and add a series of control variables measuring regional characteristics in the initial time period (2000), thereby allow for differences in trends in the level of floorspace associated with these initial conditions. Finally, in regression 9 we combine the control variables from regression 7 and 8. We use regression 9 as the baseline specification in the remainder of the paper.

Table 3: Measuring Space and Additional Controls

Regression No.	**5**	**6**	**7**	**8**	**9**
Dependent variable	**Δarea (m^2) per hereditament**	**Δarea (m^2) per employee**	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**
Broadband Speed	-0.002***	-0.006***	-0.010***	-0.008***	-0.007***
	(0.000)	(0.002)	(0.001)	(0.001)	(0.001)
ΔOutput				0.022***	
				(0.007)	
ΔPrice of Capital	0.055***	-0.603***	-0.076**	0.031	-0.068*
	(0.017)	(0.086)	(0.038)	(0.037)	(0.039)
ΔOutput/m^2 area	0.013***				
	(0.003)				
ΔOutput/Employment		0.052***			
		(0.018)			
ΔEmployment			0.155***		0.157***
			(0.016)		(0.016)
Average Wage$_{t-1}$				-0.118**	-0.117**
				(0.048)	(0.047)
Working Age Pop$_{t-1}$				-0.038***	-0.030***
				(0.011)	(0.011)
R^2	0.058	0.077	0.17	0.098	0.184
Observations	1026	1023	1023	993	990

Notes: Regression for the change in the area (m^2) of commercial properties (per hereditament in regression 5 and over total employment in regression 6) between 2000 and 2012 within a UK local authority by type (office, retail and industrial)

Of the control variables, most are statistically significant. In regression 4 we find, unsurprisingly, that regions with the largest increase in m^2 were those with the largest increase in the number of business properties. We note that the coefficient on this variable is significantly below one, indicating that new business properties tend to be smaller than older business properties. In regression 5 we find evidence that it is indeed easiest to add new commercial floorspace into regions that are initially more sparsely populated, the negative coefficient on this variable indicating convergence in the stock of properties across regions. In regression 5 we find that capital productivity, the change in the sales per hereditament has a positive effect on changes in m^2 per hereditament, as are changes in labour productivity on m^2 per employee in regression 6. In regression 7 we find that commercial floorpsace is positively correlated with increases in employment and negatively with increases in the price of building capital.

We use regression 8 to control for further characteristics of the local authority including initial income levels (captured by average wages) and the size of the agglomeration (measured by the working age population).[13] These income and size variables help control for differences in trends in building capital.[14] These variables both have statistically significant effects on the change in building capital within a region, with the smallest change in initially rich and larger populations. These results also hold in regression 9 where we replace the change in output with employment.

Throughout these regressions broadband speed remains statistically significant and indicates that faster speeds are associated with declines in building capital. These are consistent with an interpretation of capital biased technical change. Using the results from regression 9 would imply that for every unit increase in broadband speed would be associated with a decline in total m^2 of 0.7%. Over time broadband speeds have increased to 15.5mbps on average across regions. This would indicate a decline in total floorspace by 10.5%. This equates to a total commercial floorspace that is over 60% of the total in London in the year 2000.

6. Robustness

Types of Building Capital

Having established the robustness of the initial finding of capital augmenting technical change on building capital we next consider whether this has affected all industries to a similar extent. In regression 10 to 12 we report results using the three types of hereditament in the data, office space (regression 10), retail space (regression 11) and industrial properties (regression 12), separately. The results suggest that there results are indeed differences across industries. ICT has changed the space requirements for offices and industrial units to a similar extent, but quite differently to retail. Each increase in broadband speeds of 1mbps is associated with a decline of the available commercial m^2 area of office

[13] Local authorities within the UK have control over local planning applications and therefore the location and size of business properties. To remove the possibility that local differences in the acceptance or rejection of changes to commercial properties can account for our results we add a control for the refusal rate of local planning application following Cheshire (2018). The results are unaffected by the inclusion of this variable.

[14] The results for broadband remain robust if we remove the price of capital and/or the sales variable over concerns that their estimated coefficients may suffer from endogeneity bias. In this regression we include initial income, initial population and the change in unemployment to control for region specific shocks. An approach of this type is typical in studies of skill biased technical change from ICT using cost shares or factor demand shares (O'Mahony et al. 2008).

and industrial properties by 1% and 0.8% respectively, whereas for retail the same change is 0.3%.

This might indicate that the effects of ICT on the retail sector are realised primarily through changes in the number of employees required and that the building capital requirements follow from this. We extend this to explore the effects of ICT on the average m^2 area per hereditament (regression 13) and m^2 area per employee (regression 14). For these regressions we find that differences in broadband speed across different regions have no effect on building capital in the retail sector.[15] It might alternatively be that these changes have occurred in all regions and with lower internet speeds and therefore this correlates weakly with the cross-sectional variation that undegrids our estimates.

Table 4: Results by type of hereditament

Regression No.	**10**	**11**	**12**	**13**	**14**
Dependent variable	**∆area (m^2)**	**∆area (m^2)**	**∆area (m^2)**	**∆area (m^2) per hereditament**	**∆area (m^2) per employee**
Hereditament Type	**Office**	**Retail**	**Industrial**	**Retail**	**Retail**
Broadband Speed	-0.010***	-0.003**	-0.008***	0.000	0.001
	(0.003)	(0.001)	(0.003)	(0.000)	(0.003)
∆Employment	0.139*	0.039**	0.052		
	(0.080)	(0.020)	(0.040)		
∆Price of capital	0.161**	-0.064	-0.163	-0.020**	0.023
	(0.060)	(0.060)	(0.110)	(0.010)	(0.140)
Average wage$_{t-1}$	-0.031	0.026	-0.252**		
	(0.080)	(0.050)	(0.100)		
Working age pop$_{t-1}$	-0.042*	-0.01	-0.067***		
	(0.020)	(0.010)	(0.020)		
∆Output/m^2 area				0.000	
				(0.000)	
∆Output/Employment					-0.01
					(0.070)
R^2	0.169	0.049	0.226	0.021	0.074
Observations	330	330	330	342	341

Notes: Regression for the change in the area (m^2) of commercial properties (per hereditament in regression 13 and over total employment in regression 14) between 2000 and 2012 within a UK local authority by type (office, retail and industrial).

Measurement of Broadband and Types of ICT

[15] Using equivalent measures of average size or space per worker for office or industrial units we continue to find strong negative effects of ICT.

In Table 5 we test the robustness of our results to changes in the measurement of broadband and controlling for other types of ICT. In regression 16 and 17 we test whether the results are similar when we replace the broadband speed variable with broadband or superfast broadband penetration amongst households within the local area. In both regressions we find that increased broadband use within the region is associated with larger decreases in the available commercial area.

In regression 18 we consider whether the results are specific to broadband or whether they capture some other feature of ICT. To remove the effects of other features of ICT we control for the number of PCs. Of interest we find that the estimated relationship of this variable with broadband is positive. This would tend to confirm the view that ICT is a heterogeneous capital.[16] In this regression the result from broadband connection speeds on ICT remains.

Reductions in the commercial space requirements are likely to come about from a number of different changes, including simply shifting the location of the working environment elsewhere. In regressions 19 to 22 add a measure of working from home within the region. This variable differs across regions but not across industries. For this reason, in addition to its effects on the full sample (regression 19), we consider separately its effects on office (regression 20), retail (regression 21) and industrial (regression 22) properties. We anticipate that the effects of this variable should be strongest for office, where the opportunities for working from home are greatest.

We find a number of interesting results for this variable. In regression 19 we find that both broadband internet speeds and working from home help to reduce the commercial area requirements. This is revealing as it suggests that reductions in building capital do not arise just from 'hot-desking', but are broader than this. As expected we also find that this result holds most strongly for office space, whereas the measure of working from home does not help to explain declines in commercial space requirements in retail and industrial units.

[16] The results for broadband remain robust to the inclusion of alternative measures of ICT including ERP, the total number of servers or PC per employee. By themselves none of these control variables are statistically insignificant.

Table 5: Further robustness tests

Regression No.	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Dependent variable	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**	**Δarea (m^2)**
Hereditament Type	**All**	**All**	**All**	**All**	**Office**	**Retail**	**Industry**
Broadband speed			-0.005***	-0.009***	-0.014***	-0.004**	-0.007**
			(0.002)	(0.002)	(0.003)	(0.002)	(0.003)
Broadband penetration	-0.363***						
	(0.120)						
Superfast Broadband penetration		-0.432**					
		(0.180)					
Total PCs			0.011***				
			(0.004)				
Working from home				-0.043**	-0.100***	-0.029	0.037
				(0.020)	(0.030)	(0.020)	(0.030)
ΔEmployment	0.160***	0.159***	0.148***	0.158***	0.141*	0.040**	0.051
	(0.020)	(0.020)	(0.020)	(0.020)	(0.080)	(0.020)	(0.040)
ΔPrice of capital	-0.055	-0.059	-0.086*	-0.073*	0.130**	-0.059	-0.165
	(0.040)	(0.040)	(0.040)	(0.040)	(0.060)	(0.060)	(0.110)
Average wage$_{t-1}$	-0.096*	-0.147***	-0.181***	-0.093*	0.014	0.041	-0.272***
	(0.050)	(0.050)	(0.050)	(0.050)	(0.080)	(0.050)	(0.100)
Working age pop$_{t-1}$	-0.050***	-0.046***	-0.036***	0.006	0.043	0.014	-0.098***
	(0.010)	(0.010)	(0.010)	(0.020)	(0.040)	(0.020)	(0.030)
R^2	0.173	0.168	0.166	0.188	0.185	0.055	0.229
Observations	1005	1005	753	990	330	330	330

Notes: Regression for the change in the area (m^2) of commercial properties between 2000 and 2012 within a UK local authority by type (office, retail and industrial).

Instrumental Variable Estimation and Falsification Test

Throughout Table 4 and 5 our approach to the potential endogeneity bias associated with estimated effect of broadband on business capital has been dealt with firstly by removing time invariant regional characteristics by first differencing the data and by assuming that any permanent differences in growth are correlated with observable time varying or initial characteristics. In Table 6 we present evidence using an instrumental variable approach and the results for the size of residential property as a falsification test.

A remaining concern is for the presence of unobservable region specific changes that may confound our results. As described in the introduction, our time period coincides with an increase in the popularity of living in the city-centre, in part due to the attraction of fast internet speeds. This in turn has affected the competition for land within the city-centre raising, affecting prices and therefore possibly encouraging some firms to move to cheaper areas. This change in the popularity for city-centre living is likely to vary across cities due to unobservable city-centre amenities and attractiveness of the centre. The positive correlation between residential city-dwelling with internet speeds, and the negative correlation with land prices and therefore building capital would indicate that our estimates are likely to biased towards zero. In addition, the UK planning decisions are also made at the local level by committees of local politicians and often do so in an inconsistent way across time (Cheshire, 2018).

The instruments we use are based on the configuration of the telephone network, which is the infrastructure through which most types of internet are delivered in the UK. Built largely around the start of the 20th century and then during its expansion post war, this network has a tree like structure. Firms and households are connected to aggregators at the street and then local level through fixed wire connections (mostly copper but now also copper and fibre). There local aggregators, known as telephone exchanges, are then connected onto the fibre optic backbone of the network. It is well known that the cable distance from the firm or household to the local telephone exchange, known as local loops, has a strong effect on broadband connections speeds. This has been exploited as instruments for firm level broadband decisions by De Stefano et al. (2018).

To instrument for the average broadband speed within a local authority we use the distribution of local loop lengths across telephone exchanges. We estimate these regressions for all hereditament types and given the results in Table 5, excluding the retail sector. As shown from the first stage regressions (regressions 23 and 25 in Table 6) local-loop lengths are a strong predictor of broadband speeds. Regions in which the distribution of local loop lengths is greatest have slower broadband speeds on average. The F-stat is comfortably above the critical values for weak instruments.

The second stage results indicate that the effect of broadband on capital was indeed biased towards zero. We now find that capital augmenting technical change both for the whole sample (regression 24) and for office and industrial sectors (regression 26). In regression 24 (regression 26) the results suggest that an increase in broadband speeds of 1mbps is associated with a 1.6% (2.0%) decrease in building capital.

Table 6: Instrumental variable regressions and falsification test

Regression No.	**22**	**23**	**24**	**25**	**26**	**27**
Estimation Method	**IV** **First Stage**	**IV** **Second Stage**	**IV** **First Stage**	**IV** **Second Stage**	**OLS**	**IV** **Second Stage**
Dependent variable	**Broadband Speed**	**Δarea (m²)**	**Broadband Speed**	**Δarea (m²)**	**Δarea (m²)**	**Δarea (m²)**
Hereditament Type	**All**	**All**	**Office & Industrial**	**Office & Industrial**	**Houses & flats**	**Houses & flats**
Broadband speed		-0.016***		-0.020***	0.001***	0.001
		(0.003)		(0.005)	(0.000)	(0.001)
ΔEmployment	0.033	0.148***	-0.452	0.259***		
	(0.299)	(0.020)	(0.406)	(0.030)		
ΔPrice of capital	-3.516***	-0.104**	-3.684***	-0.032		
	(0.719)	(0.040)	(0.859)	(0.070)		
Average wage$_{t-1}$	6.907***	-0.03	6.550***	-0.061		
	(0.900)	(0.060)	(1.110)	(0.080)		
Working age pop$_{t-1}$	2.556***	0.002	2.552***	0.001	0.029*	0.032**
	(0.234)	(0.020)	(0.287)	(0.020)	(0.015)	(0.015)
Local loop lengths	-1.521***		-1.510***		0.010***	0.011**
	(0.104)		(0.127)		(0.003)	(0.005)
R^2	0.476	0.144	0.246	0.247	0.195	0.186
F-stat on excluded instruments	213.45		140.42			
Observations	891	891	594	594	330	297

Notes: Regression for the change in the area (m^2) of commercial properties between 2000 and 2012 within a UK local authority by type (office, retail and industrial).

The evidence presented thus far is consistent with the causal interpretation that faster broadband connection speeds are associated with capital biased technical change by reducing the building capital required to produce a given level of output. The reliability of this conclusion rests on the absence of region specific shocks, such as those to productivity, incomes or prices that encourage investment in faster broadband speeds within a region along with changes in the shape of commercial properties. If these time varying region specific shocks are present it seems reasonable to anticipate that they would also be correlated with changes in the shape of other types of property such as residential property. For example, any unobservable local price or income shocks that make business property more expensive or a region wealthier, they should have a similar effect on residential property.

In regressions 26 and 27 we explore this point using data from the ONS on the average size of residential dwellings, specifically those on detached, semi-detached and terraced houses and flats. This data is available annually for the years between 2004 to 2016 and so we use a long differenced regression over the 8-years between 2012 and 2004 to match as closely as possible the data on commercial properties. In regression 26 we report the results from an OLS regression and in regression 27 an instrumental variable regression using the distribution of local loop distances as an instrument.

The results in both of these regressions point strongly against the presence of region specific shocks. In contrast to the effects on commercial property we find that the average size of residential property *increases* with broadband internet speeds. This positive relationship continues to hold when we instrument for connection speeds in regression 27, although the effect is poorly identified such that the estimated coefficient, while identical in size, is statistically insignificant. This result also holds if we focus only on houses and exclude flats.[17]

Disaggregated Hereditament Data

For two years within our data period, 2010 and 2017, the UK Valuation Office have made available micro data on business hereditaments. This includes information about each individual hereditament including their footprint, rateable value, local etc. Using the data at this level of aggregation has both advantages and disadvantages for our question and empirical approach. An advantage is that it allows us to further consider the possible

[17] These results are available on request.

endogeneity bias of the estimated effect of broadband speed. The disadvantages comes from our use of a long differenced regression and that the VOA data has no business identifiers and so cannot be matched to employment data. As the micro level data confirm, changes in commercial footprint at the local authority level we have used thus fart occur overwhelmingly through the entry and exit margin as new hereditaments are built or older ones are reconfigured for new uses. Very little adjustment happens in the m^2 of individual hereditaments, such that, in the absence of employment changes, the cross time change in most of the data is zero. To avoid issues about how to deal with the entry and exit of hereditaments and the preponderance of zeros we aggregate to the #-digit postcode level. At the level there are 133,487 postcodes, indicating that we are operating at a much more disaggregated level than the rest of the paper. In this way, by first differencing the data we remove the effect of unobservable time invariant geographic characteristics that occur within local authorities that might have previously explained our findings. We also include local authority fixed effects to account for differences in trends in business properties at this level.

We report the results for the change in the area of hereditament using the #-digit postcode data in Table 7, where adjust the control variables across 28 to 30 in the table. In all of these regressions we continue to find evidence that changes in commercial floorspace is negatively correlated with broadband speeds, even when using data across very fine geographies.[18] We also note that the estimated coefficient is very similar in magnitude to that for the baseline regression in the table, indicating that our previous findings we strongly affected by more finely grained geographic features.

In regressions 31 to 34 we are able to more closely follow the instrumental variable approach found in De Stefano et al. (2018) and instrument for broadband speed using information on whether the postcode is attached to a telephone exchange enabled for fibre-broadband and the cable distance of the postcode to the telephone exchange. As in that paper we anticipate that broadband speeds are likely to be faster if the telephone exchange is enabled for fibre-broadband, but slower the greater the cable distance to the telephone exchange (regressions 31 and 33). The first stage regressions in the table are consistent with this. The F-stats on these instruments are also very large, suggesting no problems of weak instruments. In the second stage results (regressions 32 and 34) we continue to find strong evidence of a negative effect of broadband speeds, consistent with capital biased technical change.

[18] For broadband speed we use the change in speeds measured at the postcode level and then aggregated to the #-digit postcode level. These data are from OFCOM as in the main body of the paper, although the earliest year they are available is 2012. The data therefore measures the change in speed over the 5-year period between 2012 and 2017.

Table 7: Disaggregated Data

Regression No.	28	29	30	31 *First Stage*	32 *Second Stage*	33 *First Stage*	34 *Second Stage*
Dependent variable		**Δarea (m^2)**		***ΔBroadband speed***	**Δarea (m^2)**	***ΔBroadband speed***	**Δarea (m^2)**
ΔBroadband speed	-0.006***	-0.004***	-0.007***		-0.013***		-0.014***
	(0.001)	(0.001)	(0.001)		(0.004)		(0.004)
ΔPrice of capital	0.811***	0.717***	0.810***	-0.035***	0.801***	-0.035***	0.800***
	(0.006)	(0.007)	(0.006)	(0.005)	(0.007)	(0.005)	(0.007)
ΔHereditament		0.228***					
		(0.007)					
$Floorspace_{t-1}$			-0.003***			-0.057***	-0.003***
			(0.001)			(0.002)	(0.001)
ΔFibre Availability				0.388***		0.368***	
				(0.052)		(0.052)	
*ΔFibre Availability * Local Loop Length*				-0.057***		-0.055***	
				(0.008)		(0.008)	
Local Loop Length				0.319***		0.309***	
				(0.004)		(0.004)	
F-stat on excluded instruments					2,781.54		2,781.54
Hansen J statistic p-value					0.84		0.83
Local Authority FEs	Y	Y	Y	Y	Y	Y	Y
Observations	133,487	133,487	133,487	96,996	96,996	96,996	96,996

Notes: Regression for the change in the area (m^2) of industrial, office and retail commercial properties between 2010 and 2017 within a UK postcode. Standard errors are clustered at the postcode level.

7. Relocation and Agglomeration

The negative effect from faster broadband connections on the change in business capital revealed by our estimations implies an impact on the spatial organisation of production. As shown in Figure 5, the fastest broadband speeds in the UK are found in urban agglomerations. This implies that business activity has become more concentrated, which may have occurred in part because firms originally from outside of the region have moved.

That ICT might have led to increased agglomeration through this channel, contrasts with the more general finding in the literature, which is that ICT has led to the dispersion of economic activity. As a communication technology affects the ability to share knowledge and communicate over longer distances. Ioannides et al. (2011) demonstrate that this has led the distribution of city sizes to have become flatter in the UK.

Table 8: Relocation and Agglomeration

Regression No. ***Dependent variable*** ***Hereditament Type***	**35** **Δarea (m²)** **All**	**36** **ΔNumber of firms** **All**	**37** **ΔEmployment** **All**	**38** **ΔOutput** **All**
Broadband speed	-0.007***	-0.003**	-0.007***	0.004
	(0.002)	(0.000)	(0.000)	(0.010)
Broadband speed in neighbouring LAs	0.001			
	(0.002)			
Space (m²) per employee		-0.245***	-0.923***	-0.386***
		(0.020)	(0.020)	(0.080)
ΔEmployment	0.160***			
	(0.020)			
ΔPrice of capital	-0.088**			
	(0.040)			
Average wage$_{t-1}$	-0.130***	0.005	-0.110**	0.114
	(0.050)	(0.050)	(0.050)	(0.240)
Working age pop$_{t-1}$	-0.034***	-0.018*	-0.039***	-0.112**
	(0.010)	(0.010)	(0.010)	(0.050)
R^2	0.186	0.149	0.787	0.035
Observations	930	990	990	990

In this final section of the paper we explore this issue in two alternative ways. Firstly, we allow for the possibility we capture the shuffling of business properties across space by adding a measure of average broadband speeds in contiguous local authorities. This idea draws on Redding and Turner (2015) who discuss the issue in relation to the effect of infrastructure on the reorganisation of production. They simplify the issue and suggest separating regions into three groups; the treated region, who are subject to the benefits of the infrastructure and any displacement effects from elsewhere, untreated regions, who are near treated regions and suffer displacement effects, and a residual group of regions who neither benefit from the infrastructure or displacement effects. Under an assumption that displacement effects are confined to neighbouring regions, then the coefficient on the variable measure broadband speed in contiguous regions will be negative, if displacement effects are strong. The results reported in regression 35 suggest that this is not a strong explanation of our results. The coefficient estimate is positive, but the coefficient is close to zero and far from significance as standard levels.

In the final three regressions we measure changes economic activity within the region by the change in the number of firms (regression 36), the change in the level of employment (regression 37) and the change in the level of output (regression 38). Along with some basic controls we include in these regressions the measure of broadband speed along with space per employee. Consistent with evidence from elsewhere in the existing literature that faster broadband speed connections help to disperse economic activity we find in regressions 36 and 37 that this enters the regression with a significant and negative coefficient. There is no such effect from broadband on the change in output (regression 38). The area per employee also has a negative effect on these measures of economic mass, suggesting that falls in the area allowed for by each employee tends to increase the number of firms, the level of employment and the level of output within a region. This result is consistent with the idea that this form of capital saving technical change increases the agglomeration of economic activity, and this serves to offset the dispersing effects of ICT.

8. Conclusion

In this paper we consider whether ICT shares a similar property of past general purpose technologies and has led to capital saving technical change. Exploiting variation in broadband connection speeds across locations and across time and new data on building capital for the UK we find evidence consistent with this hypothesis. Locations with faster broadband connections speeds have been subject to the largest decrease in building capital. This result is robust to considerations of endogeneity bias explained by time invariant regional characteristics and by observable regional characteristics along with those correlated with initial conditions. The results are also robust to the use of an instrumental variable approach exploiting exogenous regional variation in the telephone network on which most broadband internet connection rely. We also find evidence that this capital biased technical change has mattered more industries reliant on office and industrial buildings as opposed to in retail sectors.

That ICT leads to capital saving suggests a new interpretation on some important current economic topics. Firstly, standard estimates of total factor productivity often ignore this type of capital, or assume it to be constant. This suggests that estimates of TFP are likely to be over-estimated as they underestimate the growth of capital services from buildings. Using ONS estimates of capital services for non-residential buildings in the UK between 2000 and 2012[19] and applying a back-of the-envelope increase of 10% in the productive stock suggested by our econometric estimates would imply growth of capital services of 4.7% per annum as compared to official estimates of 3.9%. This would imply the decline in TFP over the last decade may be worse than originally feared. Second, there has been a recent discussion of the 'death of the high street', as traditional bricks and mortar retailers face increased competition from those using on-line platforms. As a consequence various solutions have been proposed. Our results suggest an alternative interpretation. If this is the consequence of capital biased technical change, then this strongly suggests that this capital be reconfigured for other uses or scrapped.

[19] These data are available from https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/capitalservicesestimates

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Table A1: Instrumental variable regressions and results for employment

Regression No.	**27**	**28**	**29**	**30**
Estimation method	**OLS**	**IV**	**OLS**	**IV**
Dependent variable	**ΔEmployment**	**ΔEmployment**	**ΔEmployment**	**ΔEmployment**
Hereditament Type	**All Sectors**	**All Sectors**	**Office & Industrial**	**Office & Industrial**
Broadband speed	-0.006***	-0.009**	-0.005**	-0.009*
	(0.002)	(0.004)	(0.002)	(0.005)
ΔEmployment	0.112***	0.114***	0.110***	0.112***
	(0.020)	(0.020)	(0.020)	(0.020)
ΔPrice of capital	0.027	0.024	0.023	0.02
	(0.020)	(0.020)	(0.020)	(0.020)
Working age pop$_{t-1}$			-0.003	0.009
			(0.020)	(0.030)
R^2	0.065	0.066	0.063	0.063
F-stat on excluded instruments		391.25		265.04
Observations	934	844	910	820

Notes: Regression for the change in floorspace between 2000 and 2012 within a UK local authority by type (office, retail and industrial).