Internet Infrastructure effect on firm behaviour: Evidence from UK ADSL broadband rollout

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Abstract

This thesis examines the economic impacts of broadband infrastructure on firm behaviour in the United Kingdom, focusing on firm entry and exit dynamics, firm performance, and the structural shift towards servitisation in manufacturing. It constructs a novel regional broadband access index using Ofcom data and BT ADSL local exchange activation records, which is merged with the VAT business registration database and firm-level ARDX data to assess the effects of local broadband access on firm outcomes. To address endogeneity concerns and identify causal effects, the analysis employs staggered difference-in-differences (DiD) and event-study designs.

In terms of firm dynamics, broadband rollout is associated with lower firm entry and higher firm exit. After controlling for local economic and demographic conditions, the effect on entry becomes insignificant, while the effect on exit remains significant: broadband rollout increases exits by 5.3%. These effects are concentrated in manufacturing, where entry declines and exits rise, driving the aggregate results.

In terms of firm performance, broadband access does not significantly affect average turnover or labour productivity, while its impact on employment is weakly positive. Heterogeneity analysis sheds light on this insignificance: large firms experience labour productivity increase, whereas small firms expand employment but their labour productivity decrease. Sectoral evidence shows similarly mixed effects, motor trade and retail benefit more, while sectors such as real estate experience negative impacts.

In terms of servitisation, broadband access promotes a shift towards services in manufacturing by increasing the proportion of service revenue relative to goods revenue. This effect is stronger among firms with higher levels of research and development, which amplifies the move towards a service-oriented business model.

Overall, this thesis highlights the heterogeneous impacts of broadband and digital infrastructure, showing that its effects vary across firm size, sector, and capacity for innovation, rather than delivering uniform gains.

Acknowledgements

Completing my PhD over the past six years has been a challenging journey. There were many obstacles and moments of doubt, but through these experiences, I learned and grew. Although it was not always easy, each challenge brought me closer to finishing this dissertation. This work would not have been possible without the support of many people.

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Chapter One Introduction

In the past two decades, rapid and transformative technological advancements have been instrumental in propelling economic globalisation, with the Information and Communication Technology (ICT) playing a pivotal role in this process (OECD,2008). Now, Internet connectivity and new digital technologies are transforming lives, creating opportunities, and advancing economic development around the world. These developments have significantly improved access to timely information and lowered transaction costs, boosting educational outcomes, labour force participation, income, consumption, and welfare (WTO,2020; World Bank,2023).

To harness the potential benefits of ICT and digitalisation, policymakers and industry representatives believe that having efficient broadband Internet infrastructure is crucial. Broadband Internet refers to Internet access provided at a certain high speed. From the ADSL (Asymmetric Digital Subscriber Line) Broadband period between 2000 and 2010 (Ofcom, 2004) to the Superfast Broadband Programme from 2010 to 2020 (UK government, 2021), promoting the availability of such infrastructure has been a clearly defined policy goal globally (UNTACD, 2019).

Although the benefits of broadband Internet are widely acknowledged by policymakers, empirical evidence on its actual effects remains inconclusive. At the macro level, studies generally document a positive causal impact of broadband infrastructure on economic growth (Czernich et al., 2011; Maurseth, 2018; Appiah-Otoo et al., 2021). By contrast, the micro-level evidence is far more limited and often controversial, particularly regarding the impact of broadband on firm performance (Canzian et al., 2019; De Stefano et al., 2018).

A notable gap in the literature lies in the lack of firm-level causal evidence from developed economies, especially the United Kingdom, on how broadband influences business outcomes such as entry, exit, performance, and servitisation. While broadband appears to stimulate overall economic activity, it remains unclear whether these benefits extend uniformly to all firms. In fact, technological progress may lower costs for some firms while simultaneously raising barriers for others, resulting in substantial heterogeneity across firms and industries. Moreover, many existing studies do not fully address identification challenges such as endogeneity, leaving considerable scope for further research.

Given this background, this thesis seeks to fill the gap by investigating the causal effects of broadband infrastructure—the rollout of ADSL broadband by British Telecom (BT) between 1998 and 2002—on firm entry and exit and firm performance in the United Kingdom.

The analysis is guided by three main research questions:

How does broadband access affect firm entry and exit at the local district level?

What is the causal impact of broadband availability on firm performance, particularly with respect to turnover, employment, and productivity?

How does broadband access influence the servitisation of manufacturing firms?

This thesis makes several novel contributions.

First, it develops a novel district-level broadband access index, based on the physical rollout of ADSL exchanges by British Telecom (BT). This index provides a credible source of variation and serves as the key independent variable in the empirical analyses.

Second, it is the first to examine broadband's impact on firm exit and on the servitisation of manufacturing firms in the UK context.

Third, with respect to firm performance, the thesis shifts the perspective from firm-level ICT investment to broadband as digital infrastructure, highlighting its broader role in shaping firm behaviour.

The empirical analysis is organised around three dimensions of firm behaviour: entry and exit, performance, and servitisation.

Chapter 4 analyses the effect of broadband access on firm entry and exit using VAT registration data and two-way fixed effects, supplemented by staggered difference-in-differences and eventstudy methods. Results show that broadband access significantly reduces firm entry and increases firm exit, with the latter effect remaining robust at around 5%.

Chapter 5 examines the impact of broadband access on firm performance using the ARDX database. Broadband access increases employment, with average firm size rising by about 4%, but has no significant effect on turnover or labour productivity. Heterogeneity analysis shows that large firms gain productivity advantages, whereas small firms expand employment but experience productivity losses. Exploiting the physical characteristic of ADSL, we also find that a one-kilometre reduction in copper-line distance to the local exchange raises labour productivity by about 3%.

Chapter 6 investigates the role of broadband in the servitisation of manufacturing firms using Poisson Pseudo Maximum Likelihood (PPML) estimation. Greater broadband penetration increases the ratio of service to goods revenues, with stronger effects among R&D-intensive firms. However, robustness checks show weaker results when services and goods are considered separately or when estimated with two-way fixed effects.

The remainder of the thesis is structured as follows. Chapter 2 outlines the background of ADSL broadband infrastructure in the UK. Chapter 3 reviews the related literature. Chapter 4 examines firm entry and exit, Chapter 5 focuses on firm performance and productivity, and Chapter 6 investigates servitisation. Finally, Chapter 7 concludes with a discussion of the main findings and their policy implications.

Chapter Two UK Broadband Access and Institutional Context

Before turning to the empirical analysis, this chapter provides essential background on ADSL technology and the expansion of broadband in the UK. The chapter is organised as follows. Section 2.1 outlines the main technical characteristics of ADSL broadband. Section 2.2 describes the rollout of broadband infrastructure across the UK. Section 2.3 details the construction and interpretation of the broadband access index (Z_{jt}). Section 2.4 presents tests of the exogeneity of this index and discusses its limitations. Section 2.5 introduces the difference-in-differences (DiD) framework that underpins the empirical analysis.

2.1. The ADSL technology

Over the past two decades, broadband technology in Europe has expanded significantly. Broadband technologies include digital subscriber line (DSL), cable modem, fibre, wireless, satellite, and mobile Internet (3G, 4G). Among these, one of the dominant technologies was Asymmetric Digital Subscriber Line (ADSL). From 2000 to 2010, ADSL accounted for a substantial market share due to its relatively high speeds compared to dial-up and its ability to leverage existing telephone infrastructure. After 2010, its share declined as fibre-optic broadband deployments expanded and cable networks were upgraded to offer higher speeds. Nevertheless, ADSL played a crucial role in the first decade of the 21st century, as its features enabled firms and households to connect quickly to broadband Internet, accelerating the spread of the Internet.

First of all, ADSL utilises the existing copper telephone lines for transmitting both analogue telephone signals and digital data simultaneously. This allows users to access the Internet while still being able to make voice calls on the same line. At the same time, ADSL achieves this by dividing the available bandwidth on the copper lines into separate frequency bands for voice and data. Voice signals occupy the lower frequencies, while data signals occupy higher frequencies. This separation allows for concurrent voice and data transmission without interference. By leveraging existing copper-wire telephone networks and their compatibility with ADSL, many developed countries with long-established telephone networks were able to launch and diffuse ADSL broadband relatively quickly.

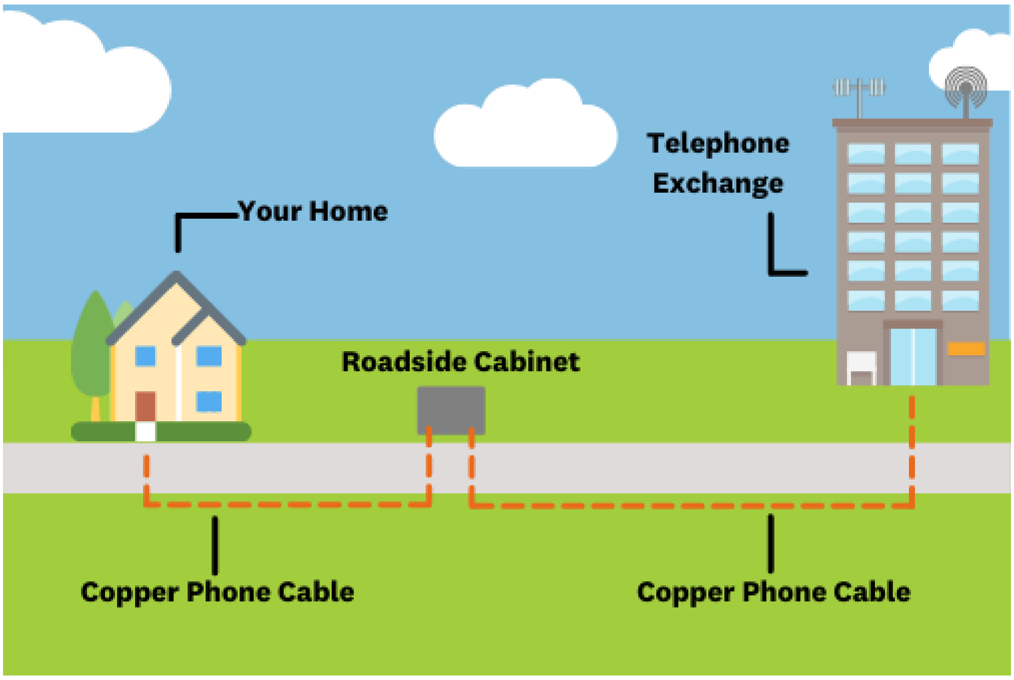
Secondly, the performance of ADSL is affected by the distance between the subscribers' locations, such as local exchanges (LEs) in the UK. Figure 2.1[1] illustrates ADSL operation between a local exchange and a firm, and Figure 2.2[2] shows how distance affects performance.

[1]*Sources*: https://getgravity.nz/blog/common-internet-terms/
[2]Sources: https://www.scgconnected.co.uk/faq/what-adsl-speeds-and-distance-can-you-expect/.

The distance between the end user and the exchange significantly impacts the Internet quality and speed of ADSL broadband. As distance increases—that is, as the copper-line loop length increases—signal quality degrades, leading to lower data rates. ADSL can deliver speeds of up to 512 kbit/s upstream and 2 Mbit/s downstream, but as loop length increases, speeds can fall to narrowband levels, typically not exceeding 56 kbit/s. This is a key characteristic of ADSL technology and provides plausibly exogenous variation in broadband Internet speeds.

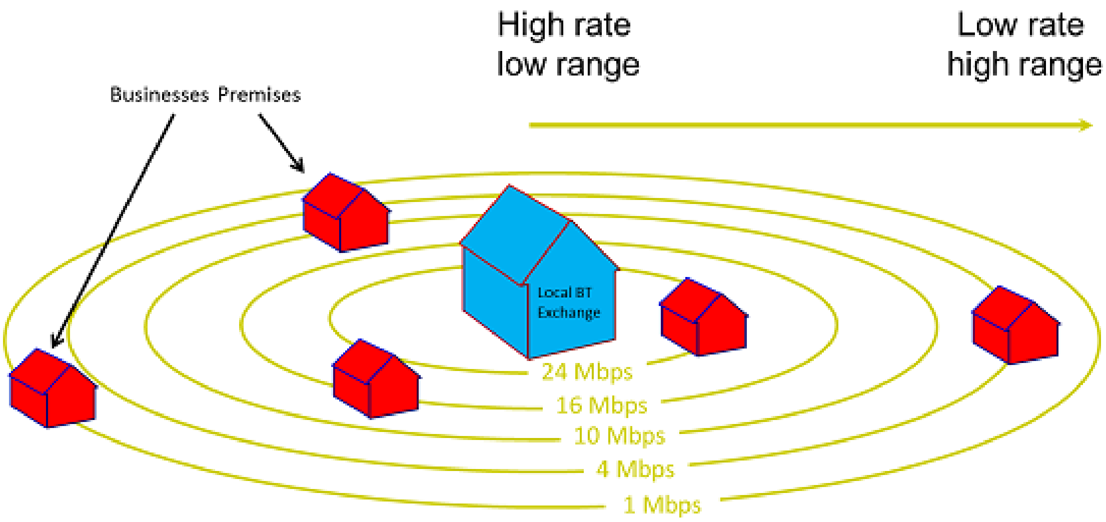
In general, broadband connections are fast, enabling quick downloads and uploads, streaming of high-definition video, online gaming, and other data-intensive activities. In contrast, narrowband connections are only suitable for basic activities such as emailing, text-based web browsing, and small file transfers, but are not ideal for data-intensive tasks. Overall, broadband enables a digital environment that supports a wider range of data-intensive activities across businesses, institutions, and households. Consequently, broadband speed and connection quality are increasingly important in the modern business environment. The attenuation of speed and connection quality with distance can therefore be exploited as a source of exogenous variation in empirical research, helping to identify the economic and business impacts of broadband infrastructure.

Figure 2.1 The ADSL firm and Local Exchange



Note: Connection is from the telephone exchange to home, which is much longer than a cabinet.

Figure 2.2 The ADSL characteristics.



2.2. The ADSL roll-out in the UK

In the UK, the roll-out of ADSL began in the late 1990s by the former national monopoly, British Telecom (BT). This section provides background on broadband deployment and describes the expansion of broadband Internet.

The development of ADSL in the United Kingdom was led by BT (British Telecommunications plc), the former state-owned monopoly operator. ADSL technology was first introduced in the UK in 1998, but it gradually became widely used as a broadband access technology from 2000 onwards. BT promoted ADSL technology by upgrading traditional telephone exchanges to enable ADSL services. In total, there are approximately 5,660 local exchanges nationwide.

Since the early 20th century, telecom services in the area surrounding Kingston-upon-Hull in the North-East of England have been delivered by a separate local provider, Kcom, rather than BT. Therefore, the Hull area is not included in our research.

The roll-out of ADSL in the UK occurred in two distinct phases. The first phase (2000-2002) was largely driven by BT's internal planning and its technical priorities, with exchanges upgraded sequentially based on BT's planning and technical feasibility. During this period, the spatial pattern of ADSL deployment was arguably more exogenous and less likely to be affected by local economic conditions.

The second phase (2003-2004), however, adopted a "demand-driven" approach. BT required a certain number of pre-registrations from local households and businesses before activating ADSL in an exchange area. This shift means that broadband infrastructure rollout in the second phase became potentially endogenous to local demand, i.e., districts with higher economic activity or more technology-aware residents may have been prioritized. This feature introduces a risk of endogeneity: broadband access index could be correlated with unobserved district characteristics, such as local economic conditions.

It is therefore crucial to acknowledge that while the initial phase of ADSL expansion can be considered relatively exogenous, the second phase introduces endogeneity problems due to its demand-driven nature. This distinction will be addressed both conceptually and through empirical robustness checks in this chapter.

Figures 2.3 to 2.5 show the timing of BT enabling local exchanges. The maps illustrate that the rollout of ADSL infrastructure across local exchanges was not simultaneous. BT initially focused on major cities such as London, Cardiff, Belfast, Coventry, Birmingham, Manchester, Leeds, Newcastle, Edinburgh, and Glasgow. The second group included cities like Hastings, Brighton, Aberdeen, Basingstoke, Carlisle, Chelmsford, Liverpool, Oxford, Portsmouth, Nottingham, York, Swindon, Royal Tunbridge Wells, Winchester, and Ashford. From 2000 to 2002, large-scale broadband access was limited to only a few local districts. (Kenneller and Timmis, 2016). It was not until the implementation of demand thresholds in 2003 that rapid expansion occurred. Due to limitations in the number of BT engineers available for upgrading exchanges and installing modems at customer premises, the deployment progressed sequentially.

Figure 2.3 UK ADSL Local Exchange enable year 1999

Figure 2.4 UK ADSL Local Exchange enable year 2001

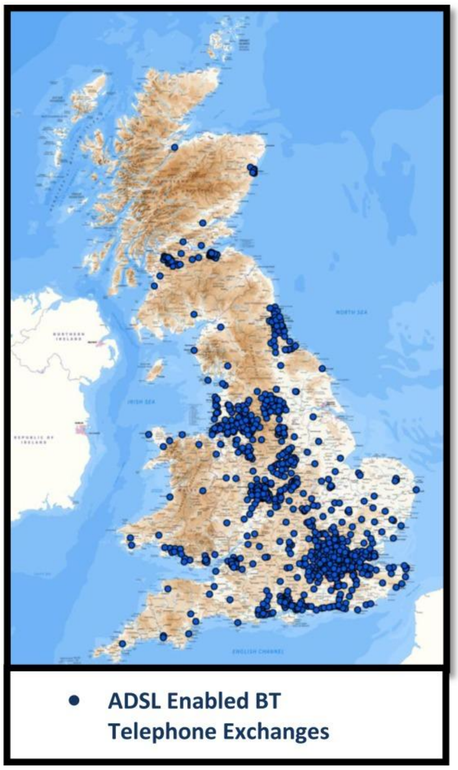
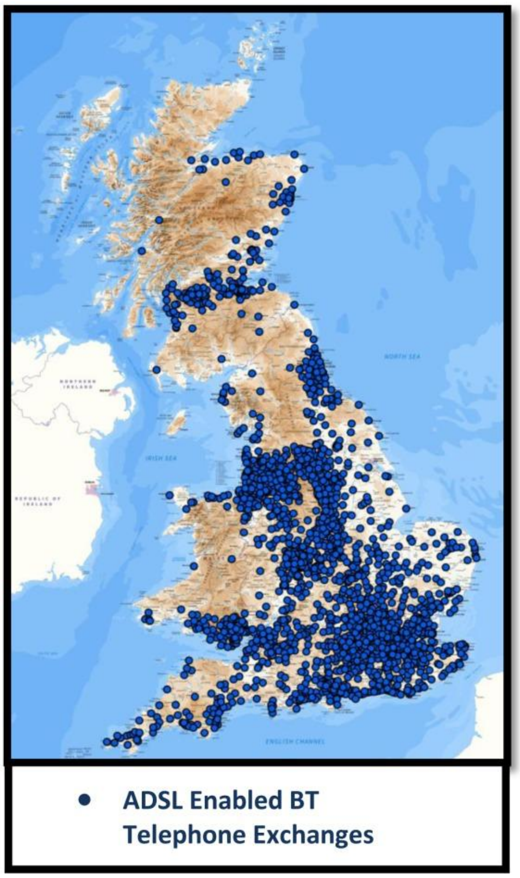


Figure 2.5 UK ADSL Local Exchange enable year 2003



Sources: Ofcom,Samknows.com[3]

2.3. Construction and Interpretation of the Broadband Access Index

To measure local broadband access, we construct a continuous index Z_{jt}. at the district (local authority) level, following Malgouyres et al. (2021). Z_{jt} reflects the share of a district's area and the share of the year covered by activated ADSL exchanges in a given year. Given that ADSL roll-out in the UK is led by BT, and coverage data is not publicly disclosed due to security concerns, we are only able to obtain a general overview of the ADSL coverage area and activation timings. Importantly, this coverage area is relatively independent of the UK's local administrative divisions. Therefore, it is not straightforward to equate ADSL activation times directly with those of corresponding cities. Consequently, we follow the methodology developed by Malgouyres et al. (2021) to devise a continuous index, Z_{jt} , representing a continuous measure of broadband access for district j in year t. This enables us to calculate the ADSL activation timing (treatment year) for each Local authority (district) j based on the

[3] http://availability.samknows.com/broadband/statistics/regional

characteristics of Z_{jt}.

Here, j represents a UK district (local authority), which is the fundamental local authority level in the two-tier UK government system. County councils are responsible for services such as education, transportation, fire and public safety, and social care within these two tiers. By contrast, district councils are responsible for responsibility for local planning, housing, local highways, buildings, environmental health, refuse collection and cemeteries. The district is the lowest level of local authority. In the UK, there are around 435 districts (ONS 2001).

Our decision to focus on the district (LA) level is primarily driven by two factors. First, the geographical scope of a district aligns most closely with the coverage area of ADSL, especially in the first phase (2000-2002), where the area covered by ADSL nearly matches the corresponding district's boundaries. Secondly, lower-level areas such as parishes and wards frequently undergo changes in their coverage areas within our sample period, making it challenging to acquire consistent data on local authority characteristics. In this thesis, "district" and "local authority" are used interchangeably.

We aim to determine Z_{jt} by using the scope of each local exchange (LE, henceforth) within each Local Authority/District. Through time and spatial weighting, we can then calculate the broadband penetration rate Z_{jt} for each Local Authority/district j. Following Malgouyres et al. (2021), we first build a continuous index of each broadband access in the local authority:

$$Z_{jt} = \sum_{b \in j}\left(\frac{number\ of\ days\ with\ activation\ in\ b\ \ since\ Jan\ 1st\ of\ year\ t}{number\ of\ days\ in\ year\ t}\right) \times \underbrace{\frac{area_{\ bt}}{\sum_{b \in j} area_{bt}}}_{A_{bt}} \tag{2.1}$$

where $b \in j$ represents the area of the local census block (we use lower super output areas (LSOAs) as our census blocks from UK census 2001) within Local authority j . Every Local Authority in the UK is divided into census blocks.

Z_{jt} is a continuous variable ranging from 0 to 1, representing the time-weighted, area-weighted share of broadband coverage in local authority j. For example, a value of 0 indicates no broadband access throughout the year in this district, while a value of 1 represents full-year and complete broadband accessibility. Thus, if all LSOAs within a district are covered for the full year, Z_{jt} = 1, indicating that broadband access is available throughout the year and across all areas of the district.

If Z_{jt} is less than 1, it can be interpreted in two ways. The first interpretation is temporal, suggesting that ADSL broadband access was available for only part of the year (on average, across the district's area). The second interpretation is spatial, indicating that only part of the district area had ADSL broadband access during the year.

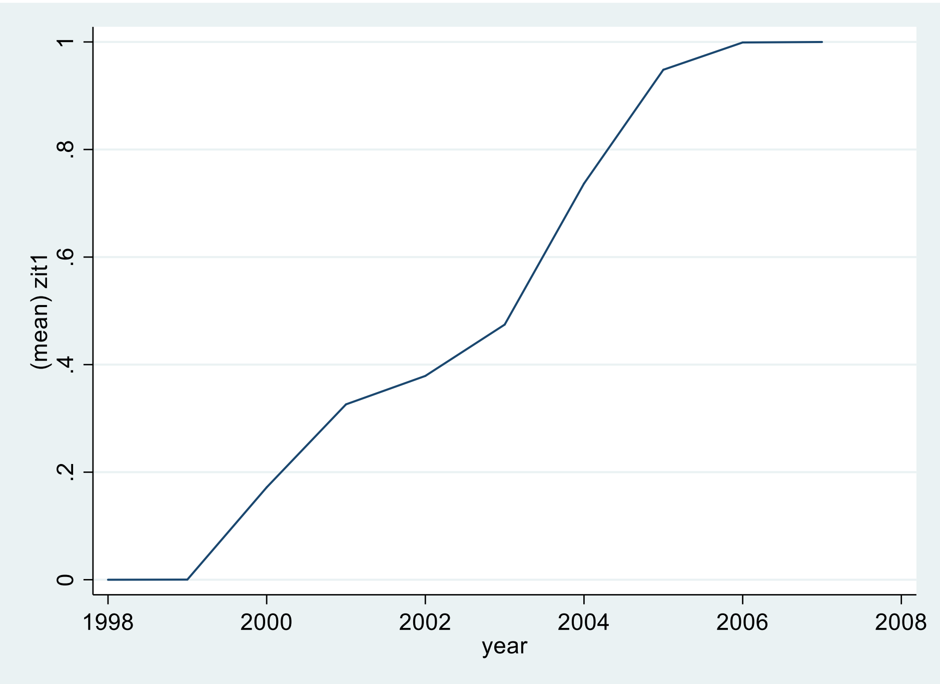
Illustrative examples:

Spatial interpretation: If 70% of the district area has access for the whole year, Z_{jt} = 0.7.

Temporal interpretation: If the entire district gets broadband from July, then Z_{jt} ≈ 0.5 (6/12 months).This index enables precise measurement of broadband rollout at the local district level, accounting for the phased and uneven nature of infrastructure expansion across both space and time.

Figure 2.6 shows the UK-level average broadband access index Z_{jt} from 2000 to 2007. It also implies there are two phases of the broadband rollout. The figure reveals two distinct stages: a gradual increase in the average broadband access index during 2000–2002 (first phase), followed by a much steeper rise from 2003 onwards (second phase), corresponding to the adoption of demand-driven activation. By 2007, most districts have achieved near-complete broadband coverage (Z_{jt}≈ 1).

Figure 2.6 Broadband Access Index, Z_{jt}.



2.4. Testing the Exogeneity of Z_{jt}: Endogeneity Checks

Given the partially demand-driven nature of the ADSL broadband rollout, especially in the second phase (2003–2004), it is essential to assess whether the variation in broadband access across districts is exogenous to pre-existing local characteristics. To address this concern, we test whether district-level socioeconomic indicators can predict broadband access in subsequent years.

Specifically, we regress the broadband access index Z_{jt} on its lagged district-level characteristics: the lagged log form of total population, the lagged log of GDP per capita, and lagged Herfindahl-Hirschman Index (HHI). The regression uses data from 1998 to 2007, with Z_{jt}starting from 1998 and lagged covariates from 1997 onward. The inclusion of early pre-rollout years helps capture the plausibly exogenous phase of the ADSL deployment.

All regressions control for district fixed effects and year fixed effects, and standard errors are clustered at the district level. The estimation equation is as follows:

$$Z_{jt} = \alpha + \beta_1 \text{lnPopulation}_{j,t-1} + \beta_2 \text{lnGDPper}_{j,t-1} + \beta_3 \text{ HHI}_{j,t-1} + \gamma_j + \delta_t + \epsilon_{jt} \quad (2.2)$$

where γ_j are district fixed effects and δ_t are year fixed effects, ϵ_{jt} standard errors are clustered at district level.

Table 2.1 Regression of Broadband Access Index Z_{jt} on Lagged District Characteristics 1998-2007.

	(1) 1998 to 2002 (Phase 1)	(2) 2003 to 2007 (Phase 2)	(3) 1998 to 2007 (Full Period)
ln_Population(t-1)	1.416	-1.569*	-0.0168
	(0.928)	(0.934)	(0.264)
ln_GDP per capita(t-1)	0.872***	-0.338	0.0383
	(0.256)	(0.243)	(0.118)
HHI(t-1)	-0.766	-4.890***	-1.677**
	(0.834)	(0.980)	(0.705)
Constant	-24.99**	23.47**	0.642
	(11.09)	(11.10)	(3.297)
Observations	1,380	1,725	3,105
R-squared	0.764	0.721	0.839
District FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 2.1 examines the relationship between the broadband access index and lagged district characteristics over two sub-periods: 1998–2002 and 2003–2007. The results indicate that in the earlier phase, the broadband access index was positively and significantly associated with lagged GDP per capita. In the later phase (2003–2007) and over the full sample period (1998–2007), the broadband access index was negatively associated with industrial concentration (HHI). Population was only weakly significant at the 10% level in the later period.

The results are partly explained by publicly available records of early rollout announcements, which show that most of the initial deployment occurred in economically stronger, medium-sized and large cities. This suggests that broadband rollout was not entirely random; rather, the source of variation was plausibly predictable and observable, being driven by structural district characteristics. Therefore, instead of assuming that broadband roll-out is completely uncorrelated with local fundamentals, this thesis assumes that, conditional on initial economic characteristics and their interactions with time, the remaining variation in the broadband access index is quasi-exogenous.

Specifically, the analysis control for the initial (pre-roll-out) values of key regional covariates, such as GDP per capita, and interacts these baseline values with year fixed effects. These interaction terms absorb systematic time-varying trends in broadband deployment that are predictable from pre-existing regional differences. Moreover, the staggered nature of broadband expansion, whereby some districts gained access earlier than others, creates a quasi-natural experiment. This setting allows the thesis to implement a difference-in-differences (DiD) framework that compares treated districts with not-yet-treated districts over time, under the assumption of parallel trends.

2.5 Construction of the Staggered Difference in Difference Model

Part One: Build the treatment indicator (Treatment Year)

In this section, we explain the motivation for employing a difference-in-differences (DiD) framework and clarify how we construct district-level treatment indicator (Treatment year) for the staggered DiD analysis.

First, randomized assignment of broadband rollout was not feasible in our institutional context. BT, the main telecommunications provider, followed a clear policy-driven expansion strategy. The earliest phase of ADSL deployment was heavily concentrated in major urban centres such as London, Manchester, Birmingham, and Edinburgh, which had stronger economic activity.

Second, the roll-out process was endogenously influenced by local economic conditions, particularly in the early phase. Our regression results in Table 2.1 confirm that broadband access index (Zjt) during 1998–2002 is significantly associated with lagged GDP per capita, suggesting that districts with stronger economies were more likely to receive early broadband deployment.

Third, despite this endogeneity, the timing of broadband activation varied across districts, due to several quasi-exogenous constraints. These constraints include the limited number of BT engineers and historical differences in pre-existing local exchange infrastructure. As a result, even districts with similar economic characteristics often received broadband access at different times. This staggered rollout provides a natural setting for applying a difference-in-differences framework.

By comparing treated and not-yet-treated districts over time and exploiting variation in treatment timing, we construct a staggered difference-in-differences (DiD) design to identify the causal effect of broadband access.

A critical step in implementing a staggered difference-in-differences (DiD) model is to define the appropriate event time—the year in which each district can be considered to have "received treatment," i.e., experienced a substantial increase in broadband access.

To do so, we build on the continuous broadband access index Z_{jt} developed in Section 2.3, which captures the time-weighted and area-weighted extent of ADSL coverage in district j in year t. Following the approach of Malgouyres et al. (2019), we define the treatment year t_{j0} for each district as the year in which Z_{jt} experienced its largest year-on-year increase. In cases where multiple years tie for the maximum increase, we assign the earliest such year to capture the initial shock. This rule is designed to reflect the point at which broadband coverage transitioned from limited access to near saturation.

Discretize continuous indices Z_{jt} and build the treatment year on the districts

We discretize our continuous index-broadband access index Z_{jt}[4] by assigning a value of 1 to the treatment status after the district experiences its largest increase in Z_{jt}. (Akerma et al., 2015; Malgouyres et al., 2019)

Specifically, we define the year of treatment (t_{j0}) as the year when Z_{jt} exhibits the maximum increase:

$$t_{j0} = \text{argmax}_t \Delta Z_{jt}.$$

We then define the treatment indicator as:

[4] $Z_{jt} = \sum_{b \in j} \left(\frac{number\ of\ days\ with\ activation\ in\ b\ since\ Jan\ 1st\ of\ year\ t}{number\ of\ days\ in\ year\ t} \right) \times \underbrace{\frac{area_{bt}}{\sum_{b \in j} area_{bt}}}_{A_{bt}}$ (2.1)

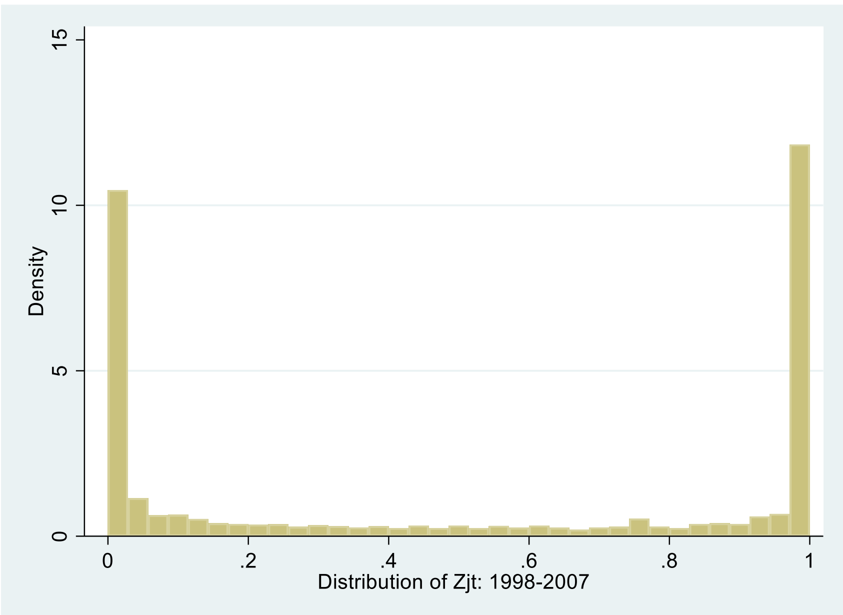
$$Treated_{jt} = 1\{t \geq t_{j0}\}$$

where $Treated_{jt} = 1$ indicates that, in year t, district j is classified as treated (i.e., the district has passed the main roll-out "jump" in broadband access).

During the ADSL activation period, although different ADSL Local exchanges within a district may have been enabled at slightly different date and with varying coverage, broadband expansion at the district level typically occurred rapidly within a single year, as reflected in official rollout figures and maps (see Figure 2.3-Figure2.5). This suggests that broadband access did not gradually accumulate over many years but instead jumped sharply from low to near-saturation levels. We provide complementary evidence from two perspectives.

First, we examine the distribution of the broadband access index Z_{jt}. Figure 2.7 illustrates the distribution of Z_{jt} across all district-year observations from 1998 to 2007, as defined in Equation (2.1). The distribution is distinctly bimodal, with a substantial mass of observations clustered near 0 and 1. This pattern reflects a high degree of polarization in broadband coverage: during the sample period, most districts were either in the early stage of broadband rollout with no or minimal access, or had already achieved near-universal coverage. The relative sparsity of observations in the mid-range (e.g., 0.1–0.9) suggests that the transition from no access to full access occurred rapidly in most districts, with little time spent in intermediate states. This feature is consistent with the institutional nature of ADSL deployment: once most local exchanges serving a district were activated, coverage expanded quickly. The discontinuous and staggered nature of the roll-out provides the basis for treating broadband expansion as a quasi-natural experiment and motivates its use for causal identification in the subsequent analysis.

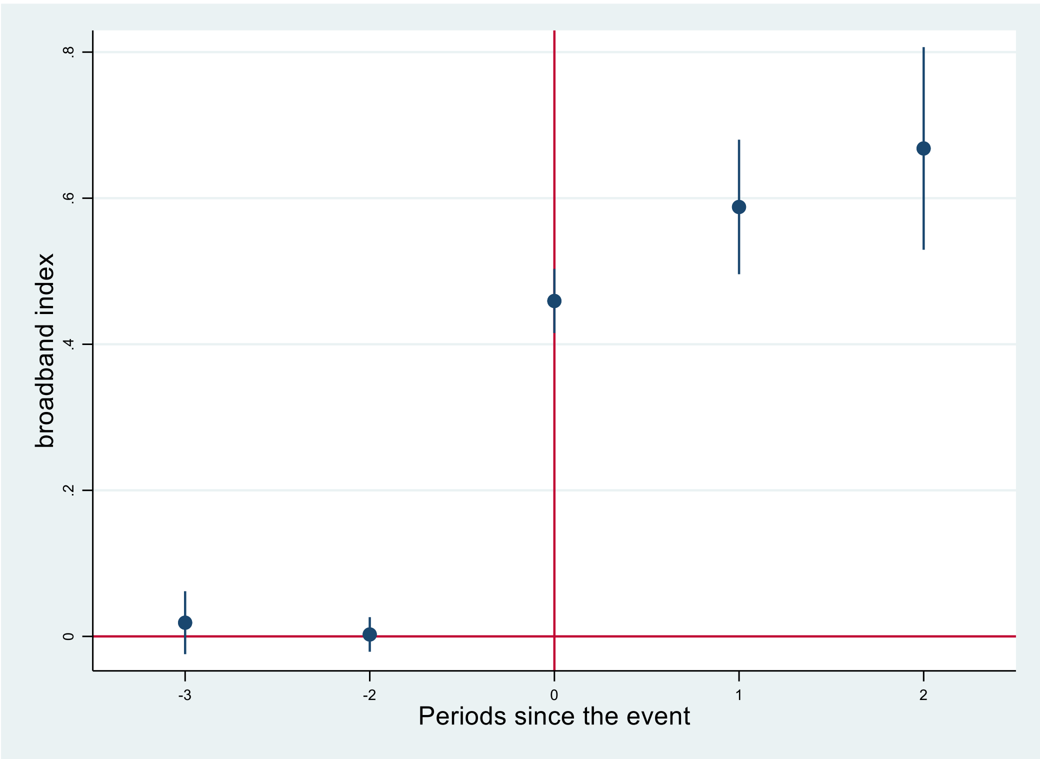
Figure 2.7 The distribution of Broadband Access Index Z_{jt}.



Second, we plot an event-study graph of the broadband index Z_{jt} relative to the constructed treatment year. The results (see Figure 2.8) show a sharp rise in broadband access index around the event year: the index increases from close to 0 in year t=−1, to approximately 0.45 in the event year (t=0), and further to 0.6 one year later. This pattern is consistent with a genuine rollout shock, with most districts experiencing a discrete and concentrated expansion in broadband availability following the identified event year.

Taken together, these two pieces of evidence confirm that defining the event year as the maximum one-year increase in Z_{jt}provides a meaningful proxy for broadband roll-out timing, justifying its use in the staggered DiD framework. This treatment-year definition also allows us to construct an event-study framework and estimate dynamic treatment effects relative to the identified roll-out year.

Figure 2.8 The evolution of continuous measure of broadband coverage Z_{jt} around the (discrete) year t_{j0} of the largest increase in Z_{jt}.



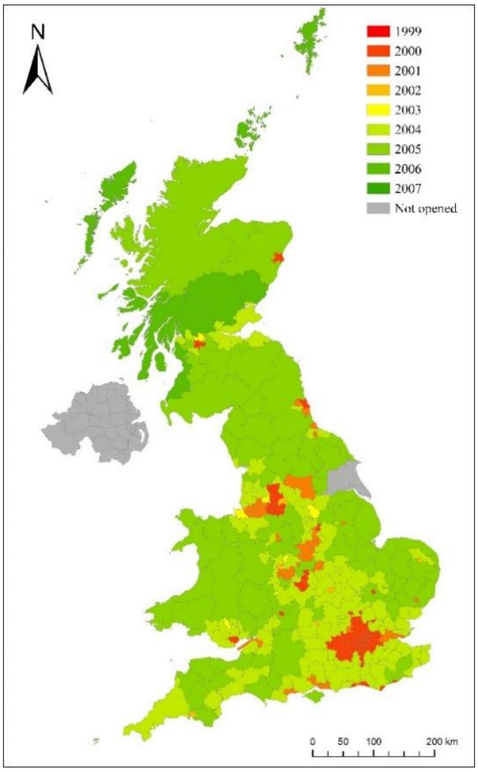
Note: This figure plots estimates from regression of Z_{jt} on set of time to broadband expansion dummies. The time at -1 is our base reference group. 95% confidence intervals are displayed.

Figure 2.8 plots the coefficients of a regression of Z_{jt} on a set of dummies for each year concerning t_{j0}. The -1 period is our base group. The results show a sharp increase, from approximately 0 at t=-1 to about 0.45 at t=1, and further to around 0.7 at t= +2.

Part Two: Geographical description of broadband

We also construct a map of treatment timing across UK districts based on the identified event year—i.e., the year of maximum annual increase in broadband coverage (Zjt). As shown in Figure 2.9, the spatial pattern of rollout timing aligns closely with BT's official ADSL exchange activation maps published during the early 2000s. Figure 2.9 shows the rollout years of broadband across the UK, excluding Northern Ireland and the Hull area (shaded in grey). The Hull area has its own local exchange operator, Kcom, while Northern Ireland lacks local exchange data. In 2000, those were confined to a few major UK districts. In 2003, the treatment had largely spread to the majority of districts.

Figure 2.9. The progressive roll-out of ADSL Broadband in the UK



Notes: This figure presents the geographical distribution of the treatment year of local broadband availability. The grey area is not included(Hull and North Ireland).

Part Three: From Traditional DiD to Staggered Treatment Framework

The primary goal of this section is to outline the method for identifying the causal impact of broadband on the dependent variables in our empirical analysis. To obtain estimates that can be credibly interpreted as causal effects, we exploit the staggered rollout of ADSL broadband across UK districts during Phase 1 (1999–2002), which followed an official commitment by BT. The quasi-exogenous nature of this rollout also has been validated by De Stefano et al. (2018), who find no evidence of manipulation during this period.

Our identification strategy rests on a conditional parallel trends assumption: in the absence of broadband, outcome trends would have evolved similarly across districts that adopted broadband at different times, conditional on district fixed effects, year fixed effects, and observed baseline covariates. To address the possibility that broadband rollout may be correlated with local economic development, for example through the earlier activation of districts with higher GDP per capita, we include a flexible set of baseline controls. This strategy mitigates concerns about potential violations of the parallel trends assumption and helps isolate variation in broadband access that can be treated as plausibly exogenous.

This identification framework underpins all our empirical analyses, including firm entry and exit, firm performance, employment, productivity, and servitisation. While our approach adjusts for observed confounders and allows for flexible differential trends, we acknowledge that causal interpretation ultimately hinges on the credibility of the parallel trends assumption, which, like in all DiD designs, remains untestable in the post-treatment period.

We begin with the traditional staggered difference-in-differences framework, implemented via the two-way fixed effects (TWFE) model, comparing outcomes across local authorities (districts) that received ADSL activation versus those that were not yet treated. As a baseline specification, we estimate:

$$Y_{jt} = a + \beta Treated_{jt} + \text{Control} + \text{FE} + \epsilon \quad (2.3)$$

where Y_{jt} is the outcome variable measured at the Local Authority (LA) level—such as firm entry, exit, or net entry in year t for district j in Chapter 4. In Chapters 5 and 6, we shift to firm-level analysis, where the outcome variable is denoted as Y_{ijt}, capturing outcomes for firm i in district j at time t, such as firm turnover, employment, or servitisation status. $Treated_{jt}$ is an indicator for whether in year t, ADSL Broadband was activated at district LA_j.

However, recent literature has raised concerns about the validity of the parallel trends assumption in staggered treatment settings. In particular, when treatment is rolled out at different times, comparing early-treated and late-treated units may yield biased estimates, especially in the presence of heterogeneous treatment effects over time (Goodman-Bacon, 2021).

To test for parallel trends and study the dynamics of treatment effects, we estimate an event-study version of the model with indicators for time relative to ADSL activation:

$$Y_{jt} = \sum_{d=-3}^{d=-1} \beta_d \times 1(t = d + t_{j0}) \quad + \sum_{d=0}^{d=2} \beta_d \times 1(t = d + t_{j0}) + Control + FE + \epsilon \quad (2.4)$$

where t_{j0} is the treatment year for district j and d indexes event time (years relative to treatment). If d is negative, which means d years before the treatment year, if d is positive, it shows the d year after treatment year. We include a vector of 3 leads and 2 lags of broadband access which range from 3 periods before broadband access until 2 periods after broadband access. β_d represent the effect of broadband access/activation, d years away from broadband access/activation and it is the main coefficient of our interest. The omitted category is $d = -1$, which serves as the reference period.

The literature also suggests that the TWFE event-study specification yields consistent estimates only under relatively strong assumptions regarding treatment effect homogeneity. (De Chaisemartin and d'Haultfoeuille, 2020; Borusyak, Jaravel, and Spiess, 2021; Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; Sun and Abraham, 2021). As shown by Goodman-Bacon (2021), the treatment effect estimate from a TWFE model is a weighted average of all possible two-group/two-period DD estimators in the data. A causal interpretation of two-way fixed effects DD estimates requires both a parallel trends assumption and a homogeneous assumption. If treatment effects are homogeneous across treated groups and over time, the TWFE estimator is a valid causal interpretation. Conversely, if treatment effects are heterogeneous across groups or time, the TWFE estimator may provide biased estimates (i.e. If an early-treated unit is used as a 'control' for many later-treated units, it may receive negative weights, which can interfere with the estimation result).

So we further explore the dynamic version using alternative approaches introduced in De Chaisemartin and d'Haultfoeuille (2020); Borusyak, Jaravel, and Spiess (2021); Callaway and Sant'Anna (2021). De Chaisemartin and d'Haultfoeuille (2020) provide the robust estimators where units are treated at different times, but do not necessarily require that treatment is an absorbing state. Their estimators (they called instantaneous treatment effects) intuitively compare changes in outcomes for units whose treatment status changed to other units whose treatment status remained constant over the same periods. Callaway and Sant'Anna (2021) extend those baseline estimators in serval direction. The key point is that they use the not-yet-treated instead of the never-treated as controls. This is very useful when there is no never-treated group. The estimators in Borusyak et al. (2021) can be obtained by running a TWFE regression of the outcome on group and time fixed effects, and fixed effects for every treated cell. Under the assumptions of the Gauss-Markov theorem, the coefficients from this regression are the linear estimators of the population coefficients with the lowest variance. Under parallel trends, the estimators in Borusyak et al. (2021) may offer precision gains with respect to those in Callaway and Sant'Anna (2021) or De Chaisemartin and d'Haultfoeuille (2020). If trends are not exactly parallel, the estimators in Borusyak et al. (2021)

may be more biased than others. (Roth et al.2023; De Chaisemartin and d'Haultfoeuille (2023).

These robust methods still restrict estimators relying on parallel trend assumptions, but that does not restrict treatment heterogeneity effect between groups and over time. Intuitively, all the estimators carefully choose valid control groups to avoid non-robust from heterogeneous treatment effects.

Chapter Three Literature Review

3.1 Broadband infrastructure and economic impact

Broadband Internet Economic Theory

Broadband technology, as a core component of Information and Communication Technology (ICT), extends the trajectory set by the early computer industry. ICT has been characterised as a General Purpose Technology (GPT) due to its widespread adoption across sectors, continuous improvements that reduce costs, and its role in enabling innovation and new processes (Bresnahan & Trajtenberg, 1995). ICT's transformative potential has been compared to that of electricity. Yet, the effect of ICT on productivity remains contested, echoing Solow's productivity paradox: despite the pervasive presence of the computer age, productivity gains are not always immediately observable (Acemoglu, 2014).

Since the Internet's emergence, research has focused on its cost-reduction mechanisms. The Internet lowers search costs, making it easier for buyers and sellers to find each other and reducing inefficiencies in transactions (Bakos, 1997; Borenstein & Saloner, 2001). Allen (2014) integrated information frictions into trade models, showing that search costs disproportionately benefit large producers. Garicano & Heaton (2010) and Bloom et al. (2014) emphasized the Internet's role in reducing internal communication costs, improving firms' exception management and decision-making efficiency. Forman & Zeebroeck (2012) highlighted broadband's role in reducing coordination costs within geographically dispersed R&D teams. Platforms aggregating customers and enabling multi-sided markets also lower search costs (Hagiu, 2012), while Kroft & Pope (2014) noted how two-sided search on online platforms facilitates matching.

The Internet also reduces replication costs, as digital information can be reproduced at near-zero marginal cost without quality loss (Goldfarb & Tucker, 2019), and transportation costs, since transmitting data is virtually free, shifting consumption toward online markets (Brynjolfsson et al., 2009; Seamans & Zhu, 2014). Reductions in tracking and verification costs are another key aspect: digital technologies enable low-cost collection of personalised data, allowing firms to price discriminate in services (Fudenberg & Villas-Boas, 2012). However, whether this intensifies competition or boosts monopoly power depends on market structure (Jerbashian & Kochanova, 2018). Overall, these mechanisms suggest that broadband and the Internet continuously reshape production, demand, and market structure.

Broadband and Economic Impact

Early macro-level studies assessed broadband's economic impact through Internet user rates or broadband penetration. Choi & Yi (2009) used data from 207 countries (1991–2000) and found a 1 percent increase in Internet users raised GDP per capita growth by 0.055 points, though this period reflected early broadband diffusion. Czernich et al. (2011) examined OECD countries (1997–2007) and found a 10-point increase in broadband penetration boosted annual per capita growth by 0.9–1.5 points. Similarly, Koutroumpis (2009) found broadband's benefits emerged significantly when penetration reached a 30% threshold. Meijers (2014) that demonstrated Internet usage fosters trade openness, which in turn drives growth, but effects were larger in high-income countries.

Several studies explored heterogeneity by national level. Dewan & Kraemer (2000) and Dedrick et al. (2013) argued ICT investment benefits were greater in developed countries, attributing this to higher IT capital stock and accumulated experience. Toader et al. (2018) found across EU countries (2000–2017) that a 1% rise in broadband usage increased per capita GDP by 0.077%. Thompson & Garbacz (2011) showed mobile broadband was especially impactful in low-income countries, while Appiah-Otoo & Song (2021) confirmed ICT benefits both rich and poor nations, but with relatively higher gains in poorer ones. Myovella et al. (2020) further indicated Sub-Saharan African countries benefited more from mobile, while OECD nations benefited more from fixed broadband.

Evidence from individual countries highlights regional nuances. Studies from the US (Holt & Jamison, 2009; Gillett et al., 2006; Crandall et al., 2007) consistently find broadband promotes growth. Outside the US, Jung & López-Azo (2019) found broadband spurred integration in Brazil's underdeveloped regions, amplified by faster speeds; Celbis & de Crombrugghe (2018) showed broadband promoted convergence in Turkish regions; and Tranos et al. (2021) found early digitalisation in UK regions had persistent positive effects on productivity over 16 years.

However, broadband economic impact is not universally positive. Greenstein & McDevitt (2009) showed broadband adoption often substituted existing technologies (like dial-up), limiting net gains. Ford (2018), using US county data, found broadband speed upgrades were unevenly distributed and did not consistently contribute to economic growth. Maurseth (2018) extended the dataset of Choi and Yi (2009) and concluded that although IT expansion positively affected growth from 1990 to 2000, the effects turned negative in later years.

Several studies have specifically examined broadband infrastructure in the UK, underscoring its economic and social significance. Riddlesden and Singleton (2014) mapped broadband speed variations and revealed a persistent urban–rural digital divide linked to distance from local exchanges. Blank et al. (2017) documented substantial geographic and demographic inequalities in broadband usage across age, income, education, and regions, highlighting the socio-economic dimensions of digital access. Dean et al. (2012) estimated that the Internet contributed 8.3% to UK GDP, demonstrating its macroeconomic importance. Ahlfeldt et al. (2017) showed that faster broadband speeds raised property values, indicating the economic premium associated with connectivity. Collectively, these studies provide a foundation for understanding the uneven diffusion of broadband and its wide-ranging impacts on UK society and the economy.

3.2 Broadband and firm performance

Differences in productivity levels between firms are quite common, and technology-driven differences are also widespread (Syverson, 2011). Although there has been extensive research on the impact of broadband on economic productivity, studies focusing on individual firms are relatively scarce, and their findings vary widely. This variation is partly due to the limited availability of data at the firm level and the challenges in addressing the endogeneity of broadband technology, which can lead to misleading conclusions.

At the same time, many studies have analysed the impact of ICT (Information and Communication Technology) on firm productivity without specifically isolating the effects of the Internet. Maliranta and Rouvinen (2006) conducted a study in Finland to examine the use of "always-available technologies" in firms. These technologies included laptops with wireless connectivity, as well as data processing and storage devices. The researchers classified the technologies based on processing and storage capacity, portability, and connectivity. Their findings suggested that processing and storage capacity could increase worker productivity by 9%, portability by nearly 32%, and both wired and wireless connectivity by 14% and 6%, respectively. Bloom et al. (2012) found that U.S. multinational firms gained higher productivity from ICT technologies, including broadband, compared to non-U.S. multinationals, using panel data from multinational companies. They attributed this to the better "people management" practices in American companies. Edquist and Henrekson (2017) conducted a study on the impact of Information and Communication Technology (ICT) on total factor productivity (TFP) growth and value added in 47 different industries in Sweden. The study categorized ICT into hardware and software, with hardware referring to communication and computing equipment. Their findings indicated a significant correlation between the growth of hardware capital and TFP growth, while the growth of software capital was closely associated with increased value added. Grimes et al. (2012) analysed cross-sectional data from New Zealand firms in 2006 to investigate the impact of broadband adoption on firm productivity.

The study used propensity score matching to account for factors influencing firms' decisions to adopt Internet access. The results revealed that broadband adoption led to a 7-10% enhancement in firm productivity. This impact was consistent across urban and rural areas, as well as high and low knowledge-intensive industries. Gal (2019) examined the impact of ICT technologies on firm productivity from a digitalisation perspective, showing that industry-level digital adoption is associated with firm-level productivity growth. The impact was relatively stronger in manufacturing and in firms with higher productivity. However, this effect was weaker in firms with lower skill levels, which the author suggests may be due to the complementarity between digital technologies and other forms of capital, such as skills, organization, or intangible assets.

The impact of broadband Internet on company performance and productivity has been a focus of recent research due to the increased availability of firm-level data. Bertschek et al. (2015) conducted a study on the effect of broadband Internet access on labour productivity at the firm level in Germany from 2001 to 2003. They controlled ICT capital and examined the causal relationship between broadband access and labour productivity. The findings suggested that, after controlling for regional economic characteristics such as GDP per capita, broadband access did not have a significant impact on labour productivity, but it did positively influence innovation. The use of broadband Internet was associated with a 7.8% increase in the likelihood of process innovation. It is possible that broadband's impact on labour productivity takes time to manifest, possibly due to a trial and learning phase, with effects emerging as firms develop new or improved products and services. Rivares et al. (2019) investigated how the use of online platforms impacts the productivity of service companies. They created measures for online platform usage in four industries (hotels, restaurants, taxis, and retail) in ten OECD countries and analysed how this affected the productivity of individual firms. Their findings showed that the use of online platforms was associated with increased productivity for existing companies and encouraged the movement of workers to more productive firms within these industries. The study also highlighted that "aggregator" platforms, which link service providers with consumers, tended to improve the productivity of established firms. Akerman et al. (2015) analysed how the availability and use of broadband in Norwegian firms from 2000 to 2008 affected labour productivity, focusing specifically on the skill levels of workers. Their findings revealed that greater broadband availability was linked to a notable increase in the efficiency of skilled workers. Additionally, they determined that the overall improvement in labour productivity was driven by the enhanced relative productivity of skilled workers. Canzian et al. (2019) conducted a study on the effects of government-led ADSL2+ broadband policy on firms at the municipal level in the Trento province of Italy. They used firm (excluding agriculture and public service sectors) and municipal panel data from 2008 to 2012. The study found that broadband availability had a significant positive impact on annual sales and value added. Local broadband deployment increased firms' revenues by approximately 14% and total factor productivity (TFP) by around 9%. At the industry level, most observed industries benefited significantly from broadband availability, particularly hotels, restaurants, and professional, scientific, technical, and administrative services. However, there was no significant increase in the impact on high-tech sectors.

However, some authors argue that broadband does not significantly affect firm productivity. Haller and Sean (2015) analysed data from the Irish manufacturing sector for the period 2002 to 2009 to investigate how the adoption of ADSL broadband technology affected firm productivity. Their study revealed that more productive firms were more inclined to adopt ADSL. However, they did not find any significant impact of broadband adoption on firm productivity growth, whether measured in terms of labour productivity or TFP. This lack of impact could be due to their focus on manufacturing firms, which might experience less productivity benefits from broadband adoption when compared to firms in the service sector. DeStefano et al. (2019) studied the influence of ICT capital on firm productivity using panel data from 2000. They employed the timing and distance of broadband activation as instrumental variables and found that while broadband activation was significantly related to ICT capital, ICT capital had no significant impact on firm TFP. In a later study, DeStefano et al. (2023) investigated the impact of broadband adoption on labour productivity. They used a regression discontinuity design that leveraged geographic discontinuities in broadband local exchange availability across the UK. Their results indicated that broadband availability had a positive and significant impact only on firm employment, with no significant impact on labour productivity.

Broadband and labour employment

Our research also focuses on labour employment in relation to broadband usage. Broadband can either replace or complement labour. Most studies indicate that broadband Internet has a positive impact on employment. Gillet et al. (2006) found that the early introduction of broadband in U.S. communities significantly increased total employment growth. However, the impact on labour employment varied by industry and region. They discovered that broadband had a greater effect on urban employment, leading to an increase in both job numbers and wages. Crandall et al. (2007) examined the impact of broadband subscription rates on employment across various industries in the U.S. using state-level panel data from 2003 to 2005. They found that broadband subscription rates had a positive effect on employment in nearly all industries, particularly in finance, education, and healthcare. Forman et al. (2012) studied the relationship between firms' Internet investments and wage and employment growth across U.S. counties from 1995 to 2000. Their study revealed that Internet investments contributed to 28% of wage growth, but this growth was concentrated in only 6% of U.S. counties, which had relatively high income, population, and skill levels. In contrast, counties with lower population densities did not see an improvement in comparative economic performance. Atasoy (2013) conducted an analysis of the U.S. labour market using data from 1997 to 2007. The study revealed that access to broadband services in a county was linked to a 1.8 percentage point increase in employment rates, with a more significant impact in rural and remote areas. Furthermore, it was noted that broadband technology complemented skilled workers, particularly those with a college education, as well as industries and occupations that employed more educated workers.

Similarly, Akerman et al. (2015) found that increased municipal broadband availability in Norway had a positive impact on the hourly wages and employment of skilled workers. Conversely, the hourly wages of low-skilled workers were negatively affected. This was attributed to firms using broadband to complement skilled workers in performing non-routine abstract tasks while substituting for unskilled workers in routine tasks. Hjort and Poulsen (2019) also found that the introduction of the fast Internet helped increase net employment in Africa, driven primarily by increased employment in high-skill occupations, with less impact on the employment of workers with lower education levels. Jayakar and Park (2013) utilized county-level data from 415 U.S. counties and found a significant negative correlation between broadband deployment and county-level unemployment rates.

However, some studies have not found positive results. Bertschek et al. (2013) studied the expansion of broadband in Germany and found a reinforcing relationship between broadband and local employment. While broadband improved the quality of employees' work, it did not necessarily have a positive impact on quantitative performance metrics. Ivus and Boland (2015) discovered that broadband deployment from 1997 to 2011 promoted total employment and average wage growth in rural Canada, but suppressed employment growth in urban areas. Bai (2017) investigated whether faster broadband speeds more effectively promoted employment compared to slower broadband across different regions of the U.S. His results showed that while faster broadband, defined as a download speed of 100 MB/s, had a more significant positive impact on employment than regular broadband, ultra-high-speed broadband (1 GB/s) had a smaller impact on employment than fast broadband. This result suggests diminishing returns to Internet speed in terms of employment benefits.

Kolko (2012) pointed out the limitations of broadband. Although broadband led to an increase in local employment numbers, he discovered that regions with faster broadband expansion between 1999 and 2006 did not necessarily experience greater increases in local employment rates or average wages per employee compared to other regions. Additionally, median household income declined, indicating that broadband did not bring direct benefits to residents, making its economic development benefits unclear. Furthermore, the relationship between broadband expansion and employment growth varied by industry, especially in finance, utilities, and information sectors. Whitecar et al. (2014) also concluded that higher broadband adoption levels (60% usage rate among residents) were positively correlated with the number of businesses and employees, yet the growth in broadband availability did not have a significant impact on employment. Michaels et al. (2014) focused on the impact of ICT technologies, including broadband, on labour market polarization. They found that broadband reduced the demand for workers with medium levels of education, increased demand for highly educated workers, and had little impact on workers with low levels of education.

In sum, our empirical findings contribute to the existing literature by providing more nuanced evidence that broadband access has heterogeneous impacts on firm performance. Our primary contribution is to offer the first dynamic, firm-level evidence for the UK that broadband access increases both firm size and turnover, particularly by documenting sustained growth in firm employment following broadband rollout. These results are consistent with the positive associations reported by Grimes et al. (2012) and Canzian et al. (2019), but go further by establishing dynamic effects over time and quantifying the intensity channel, thereby yielding more granular insights into how broadband infrastructure translates into firm-level performance. A secondary contribution is to identify heterogeneity in these effects across firm size and industry, showing that the benefits of broadband are not uniformly distributed. This dimension has been largely overlooked in prior research.

Considering that the most closely related recent study is De Stefano et al. (2018), our research differs in three important respects. First, whereas De Stefano et al. (2018) examined the association between ICT capital and productivity using several measures of ICT investment and a narrower set of performance outcomes, we exploit exogenous variation in broadband infrastructure availability, allowing for a cleaner identification of causal effects. Second, while their analysis reported no significant relationship between broadband availability and firm productivity, our findings offer an explanation for this insignificance by uncovering offsetting heterogeneity across firms. Third, whereas De Stefano et al. found that small firms disproportionately benefited from ICT capital investments such as personal computers, our results suggest that broadband, as a general-purpose infrastructure, confers greater advantages on large firms that are better positioned to leverage connectivity for expansion and coordination.

3.3 Broadband infrastructure and firm entry and exit

Certain studies, mainly based on firm location theory, indicate that areas with broadband access have a competitive edge over others, leading to a greater number of new businesses being established. Broadband access can indeed enhance the profitability of businesses in specific geographic locations in several ways. Firstly, the Internet enables businesses that were previously limited to local markets to engage in long-distance trade, thereby increasing sales by expanding their market reach (Hagiu, 2012; Lamie et al., 2011). Secondly, the Internet can reduce production costs by connecting firms to remote suppliers and enabling access to outsourced services (Leamer, 2007). Thirdly, broadband access also reduces communication costs, facilitating smoother information exchange, mutual dissemination of knowledge and ideas, and simplifying coordination costs with both internal and external partners (Forman & McElheran, 2013; Forman & van Zeebroeck, 2012). These studies have shown that digital communication enhances research collaboration within organizations. Fourthly, broadband improves labour market matching between companies and workers, shortens the recruitment process, and lowers labour costs for businesses (Autor, 2001; Kuhn & Mansour, 2014). Lastly, the Internet drives diversification in product sales, as digital technologies make inventory systems more efficient, enabling companies to promote a wider range of products, particularly non-standard items (Goldfarb et al., 2015). However, some literature has focused on market structure and product pricing, suggesting that broadband poses challenges for businesses. Brynjolfsson et al. (2009) analysed the competition between online and offline retailers, finding that the Internet reduces search costs, making consumers more likely to search for products online. Online businesses can more easily offer niche products, while physical store consumers typically focus on a few highly visible, popular products. Therefore, the Internet complements brick-and-mortar businesses when they offer niche products. However, when consumers are searching for popular products with low search costs both online and in traditional stores, competition between these two types of retailers can become very intense. Bar-Isaac et al. (2012) suggested that only companies producing the highest-quality products or niche products profit, but this comes at the expense of companies producing mid-range products, which are forced to exit the market. Lieber and Syverson (2012) illustrated how the Internet's connectivity allows remote online businesses to compete with local offline businesses by reducing the costs of distributing products across wide geographies. Although no new businesses may emerge in the local area, existing businesses may face competition from distant Internet companies, potentially leading to their exit from the market. Forman et al. (2009) highlighted the competition faced by online businesses from offline rivals, using the book industry as a case study. They found that when local competitors emerge, consumers tend to substitute online shopping with in-store purchases and become less sensitive to online price discounts. This behaviour is attributed to the high negative utility costs associated with online shopping. At the same time, the information exchange mechanisms enabled by broadband can alter the competitive landscape. For instance, while online platforms may not directly compete with offline businesses, the reduction of information asymmetry by the Internet can enhance the revenue and operational efficiency of local dining establishments (Cramer & Krueger, 2012; Luca, 2016).Despite the efficiency gains from adopting digital technologies, the impact on organizational structure in equilibrium depends on the nature of the technology and how its specific characteristics influence firm boundaries (Forman & McElheran, 2013).

These mixed influencing factors make the impact of broadband on entrepreneurship highly complex. Numerous studies have empirically tested broadband's effect on business formation, considering all industries and locations, including urban and rural areas. Most of them find a positive impact of broadband access on entrepreneurship. In the United States, Lehr (2006) examined the impact of early community-level broadband deployment between 1998 and 2002. They found that communities with broadband experienced faster growth in employment and the overall number of businesses. They also found that broadband supported specific industries, particularly IT-intensive sectors. Building on this, Gurney (2012) studied the long-term impact from 1998 to 2008, consistent with the earlier findings. Mack & Grubesic (2009) verified the correlation between broadband availability and the number of companies in Ohio between 1999 and 2004. They found that broadband access was more positively correlated with small business formation than large companies. Mack (2014) studied the impact of broadband speed on entrepreneurship by examining data from Ohio census tracts, focusing on rural areas. They found that broadband speed is particularly important for rural businesses, suggesting that broadband speed offsets the agglomeration advantage of urban areas, enabling businesses to operate in rural locations. Prieger et al. (2017), comparing different types of infrastructure (Internet connectivity), knowledge infrastructure (human capital), and transportation infrastructure (roads, bridges, and intermodal facilities), found that various types of infrastructure contribute to entrepreneurship, especially knowledge and broadband infrastructure. The importance of broadband for entrepreneurship varies by industry but is more significant in innovative sectors. When transportation and broadband infrastructure both increase, they provide additional benefits for entrepreneurship. Broadband has a more significant impact on entrepreneurship in rural areas and regions with higher unemployment rates.

While most positive effects are based on evidence from the United States, recent studies from other countries also provide supporting evidence. A study from Germany compared broadband with traditional transportation infrastructure. Audretsch et al. (2015) examined the relationship between traditional infrastructure, such as railways and highways, and broadband infrastructure with regional entrepreneurial activities. Their results show a significant positive correlation between regional entrepreneurship activities and infrastructure in the German context. They found that railway infrastructure most benefits the creation of new firms in technology-oriented services, consumer-related services, and retail trade, but is less favorable for high-tech or low-tech manufacturing. Broadband infrastructure, in particular, promoted new company formation in technology-oriented services, while highway infrastructure had no effect. McCoy et al. (2018) built on the study by Audretsch et al. (2015) to investigate the impact of infrastructure, such as highways and other infrastructure, and higher education facilities on firm entry in Ireland. They found that both initial ADSL and fibre broadband positively affected firm formation. Basic ADSL broadband availability led to an increase in both high-tech and low-tech companies, while the benefits of fibre broadband seemed concentrated in high-tech sectors. However, they found that broadband benefits were only evident in areas with higher levels of education; in regions where education levels were below a certain threshold, broadband may not effectively encourage new businesses.

However, other studies provide more contradictory conclusions or find no significant association between broadband and business establishment. Atasoy (2013) also used broadband deployment data from the United States from 1999 to 2007. Their findings only showed that broadband led to an increase in employment but had no effect on the number of businesses. The increase in employment numbers mostly came from existing businesses expanding their labour demand and workforce, rather than from the creation of new businesses. Dinterman (2016) directly assessed the impact of the USDA's Broadband Loan Program and also found no significant correlation between broadband and business formation. Mack and Sergio (2014) suggested that broadband is an important factor for businesses, especially in decentralized knowledge-intensive sectors. However, they argued that broadband should not be the only factor considered. The impact of broadband on businesses depends on the specific economic, demographic, and industrial conditions of the region. Their study, which used data from major metropolitan areas in the United States, found that in cities with lower industrial levels, broadband may compensate for the benefits of knowledge-intensive metropolitan areas. On the other hand, in cities with higher industrial levels, broadband has a significant impact, possibly helping to alleviate commuting congestion costs. In a different study, Duvivier and Bussière (2022) evaluated the effects of France's ultra-high-speed broadband program from 2013 to 2018 on municipal entrepreneurship using a pre-matched difference-in-differences approach. They found that broadband access positively impacted entrepreneurship only in municipalities with favourable initial conditions in terms of the local economic environment, natural amenities, and demographic structure. The impact was minimal in structurally weak rural areas.

While most of the existing studies have focused on the impact of broadband on firm entry, very few have considered the impact on firm exits. Recently, a few papers that are closely related to our research have examined the impact on firm exits. Hjort and Poulsen (2019) utilized the event of high-speed cable access in Africa, using data from South Africa's CIPC, which records the names, addresses, and corresponding dates of registered or deregistered companies. Their results found that when high-speed Internet reached South Africa, the net number of companies increased significantly by about 23%. This overall impact was driven by a substantial increase in business entries and a reduction in business exits. Their findings also indicated that the net entry of firms increased significantly across many industries, with the effect being more pronounced in sectors that extensively use ICT, such as finance and services.

Chen et al. (2023) investigated the impact of broadband penetration at the county level in the United States from 2000 to 2019 on firm entry and exit. Their results indicate that broadband increased the number of business entries and decreased the number of business exits. They also examined the differences in broadband's impact on urban and rural market business entries and found that broadband increased the net number of businesses in both urban and rural markets. However, the net growth in finance and insurance, information, real estate, and arts and entertainment was limited to urban markets; broadband also led to net institutional losses in rural manufacturing and hospitality, as well as urban retail.

Cambini and Lorien (2023) used the rollout of Ultra Broadband in Italy to construct a staggered difference in difference model. Their findings were contrary to previous studies, showing that broadband access led to an increase in business exits, especially for small companies. The main industries affected were hotels, restaurants, and real estate leasing, with no significant impact on large enterprises. The impact of broadband on business entries was not clear, with entries only increasing in digitally-intensive industries and the most developed geographical areas. They used business activity registration information as a proxy for business entries and exits, and broadband data was based on the percentage of households with ultra-high-speed connections.

Our results complement and extend the literature on broadband and firm behaviours by demonstrating that broadband access can simultaneously act as a catalyst for firm exits and a deterrent to new entry. Exploiting the quasi-natural experimental staggered rollout of ADSL broadband across UK districts and panel data on VAT-registered firms, our event study finds that broadband significantly increases firm exits and reduces firm entries, leading to a decline in the stock of firms, particularly in manufacturing sections. These findings stand in stark contrast to the dominant narrative in prior studies (e.g., Lehr, 2006; McCoy et al., 2018; Hjort & Poulsen, 2019; Chen et al., 2023), which emphasize broadband's positive net effects on entrepreneurship through higher entry and lower exit rates. Instead, our results align more closely with Cambini and Lorien (2023), who report increased exits in Italy, while we extend their findings by providing deeper insight into heterogeneous sectoral patterns. For example, we show that manufacturing benefits from increased entries, whereas the service and construction sectors experience elevated exits.

Our primary contribution is to demonstrate that broadband access does not uniformly spur entrepreneurial growth; rather, it can intensify market competition to the extent of forcing incumbent firms out while discouraging new entrants. This challenges the widely held assumption that digital infrastructure universally promotes firm creation and highlights a neglected downside of broadband-induced competition.

Our secondary contribution is to provide the first evidence for the UK context on the asymmetric effects of broadband on firm entry and exit across industries. In doing so, we fill an important gap in the literature, which has rarely examined both sides of firm dynamics jointly and has largely overlooked sector-specific heterogeneity.

3.4 Broadband infrastructure and firm servitisation

Servitisation

The literature we are reviewing focuses on studies exploring the concept of servitisation, primarily from management and business research. Traditionally, economists and policymakers have considered goods and services as separate entities, each with its own market dynamics and requiring distinct policies. However, this viewpoint does not align with what we observe in many cases in which servitisation involves deeply integrating the production of goods and services in manufacturing firms. The term "servitisation" was coined by

Vandermerwe and Rada in 1988. It refers to companies offering a bundled combination of goods, services, support, and knowledge, dominating the market as a comprehensive package rather than a single product offering. This definition adds value to the core product by placing services at the centre of the bundle (Brax 2005). Similarly, Oliva and Kallenberg (2003) proposed a "shift from products to services," advocating for manufacturers to integrate services into their core products. Subsequent research has presented various interpretations of servitisation, such as the engineering-led concepts of "product-service systems" (PSS). Roy and Seliger (2010) argued that companies should offer a set of saleable products and services that collectively meet user needs, characterized by the sale of product usage rights rather than the product itself, the replacement of goods with services, and a shift towards a "leasing society." In the marketing and strategic management literature, Wolfgang and Reinartz (2014) described servitisation as combining supplier and customer resources to create solutions that deliver usage value. Despite differing definitions, all these perspectives emphasize varying degrees of bundling between products and services (Lightfoot et al., 2013; Christian et al., 2017; Raddats et al., 2019).

A substantial amount of empirical literature has examined these phenomena, showing that they are prevalent and increasing in most advanced economies. However, there is limited systematic evidence from firm-level datasets to ascertain the extent or consequences of servitisation. Some authors have presented compelling evidence of the advantages of servitisation. This evidence is often based on thorough analyses of specific companies (Kastalli and Van Looy, 2013). The authors studied the impact of servitisation by examining the value creation from 2001 to 2007 in the subsidiaries of a global manufacturing company across 44 countries as it shifted towards becoming a product-service provider. Their findings revealed that product and service sales complement each other, with the proximity of service products to customers enhancing the positive impact of services on product sales. They also discovered a non-linear cubic relationship between service sales and profitability. In the early stages of servitisation and at a large scale of service operations, there was a positive correlation between the scale of services and profit margins. However, in the mid-stages of servitisation, this relationship was not significant.

Similarly, Suarez et al. (2013) studied the role of services in the financial performance of firms in the pre-packaged software product industry from 1990 to 2006. They found a convex non-linear relationship between the proportion of total sales derived from services and the overall operating profit margin of product companies. As expected, companies with very high levels of product sales had the highest profits, while an increase in service levels was associated with a decrease in profitability. However, when services accounted for the majority of a product company's sales, additional services began to have a positive marginal effect on the company's overall profits.

Kohtamäki et al. (2013) focused on the role of networks in the servitisation process. They based their study on data from 91 Finnish machinery manufacturing firms collected between 2008 and 2011. The results indicated that the impact of offering service products on sales growth was also nonlinear. Additionally, they found that social network functions, such as coordination, relational skills, partner knowledge, and internal communication, enhanced the effect of service products on sales growth.

Crozet and Milet (2017), using data from French manufacturing firms between 1997 and 2007, found that companies that began selling services experienced an increase in profitability (EBITDA) by 0.4%, a rise in employment by 2.1%, and a 0.6% increase in total sales. Smaller firms experienced greater benefits. From an industry perspective, the highest gains were seen in the agricultural products, minerals and metals, and machinery and electrical equipment sectors. However, they also noted that servitisation involves more intangible products, making it challenging to accurately quantify service output and service quality.

This reflects the hypothesis that unless companies reach a certain level of service revenue, they will not achieve higher financial returns. Fang et al. (2008) utilized panel data from 477 public listed U.S. companies between 1990 and 2005 to examine the impact of service transformation strategies on shareholder value creation. The indicator of a company's service transformation is the service ratio, which represents the portion of a company's total revenue derived from actual service sales. Firm value was measured by Tobin's q. Their results showed that service sales only have a significant positive impact on firm value after they reach a critical threshold (20%-30%). Additionally, they found that the impact of service sales on firm value depends on both the company and the industry. When service products are more closely related to the company's core business and the company has more available resources, the service transformation strategy is more effective in enhancing value. Some scholars also believe that servitisation needs to be combined with specific industries or requires additional conditions.

Valtakoski (2011) conducted case studies on multiple software product companies and performed a cross-sectional statistical study involving 116 companies within the Finnish software industry. The findings revealed that providing knowledge-intensive services affects the performance of product companies. However, the extent of this impact varies depending on the type of company. For instance, if a company is already internationalized or employs service partners, service capabilities have a notably positive effect on the performance of product companies.

Eggert et al. (2014) studied the impact of different types of services using panel data from 513 mechanical engineering companies. Their results revealed that industrial servitisation strategies not only increased the revenue levels of manufacturing firms but also enhanced the growth of revenue streams. Although these strategies reduced manufacturers' profit levels, they increased profit growth rates. The results further indicated that services supporting customers (SSC) and services supporting supplier products (SSP) influence performance outcomes in different ways. SSCs directly affect revenue and profit streams, whereas SSPs indirectly impact financial performance through SSCs.

Kohtamäki et al. (2015) utilized data from 404 Finnish industrial companies (SIC 28) in the machinery and equipment manufacturing industry in 2010. They explored the transition of Finnish industrial companies from focusing on product manufacturing to focusing on service solutions. They found that a service-oriented business, which emphasizes the importance of high-quality customer service, has a significant positive impact on both product sales performance and profit performance.

Sousa et al. (2017) used data collected by the IMSS (International Manufacturing Strategy Survey) in 2013-2014 from 22 countries. They categorized service offerings into two types: basic services (more related to the product) and complex professional services (more related to the customer). Their results indicated that complex professional services have a positive impact on financial performance, whereas basic services do not have a significant effect.

Several studies have highlighted the challenges of servitisation, contending that the necessary cultural and organizational changes often prevent companies from fully capitalizing on the opportunities presented by services (Gebauer et al., 2005). Their research revealed that despite manufacturers expanding their service offerings and incurring higher costs, this did not result in the expected higher returns, a phenomenon they termed the "service paradox of manufacturing companies." In their survey, only 11.1% of manufacturing companies generated more than 40% of their revenue from services, while over 35% earned less than 10% of their revenue from services."

Gebauer et al. (2012) delved deeper into this service paradox through qualitative analysis. They proposed that the primary reason manufacturing firms struggle to realize expected returns from investments in service business expansion is the absence of a market-oriented, well-defined service development process. Furthermore, they suggested that nurturing a strong service culture within a company could help overcome the service paradox and result in higher revenue and profits.

Visnjic et al. (2012) investigated the performance impacts of two core dimensions of servitisation. They argued that increasing service breadth (measured by the number of services offered) could have a negative impact while increasing service depth (measured by the comprehensiveness of the services offered) would lead to higher profit margins and market value.

Neely et al. (2009) analysed cross-sectional data from the OSIRIS database, which included information on 12,521 companies from 25 countries in 2007. They examined the textual descriptions in the database to identify whether manufacturing companies were involved in servitisation. The study identified 12 main types of servitisation, including design and development services, systems and solutions, retail and distribution services, maintenance and support services, installation and implementation services, financial services, property and real estate, consulting services, outsourcing and operational services, procurement services, leasing services, and transportation and freight services. The researchers' regression analysis showed that while servitisation companies had higher revenues, their percentage of net profit to revenue was often lower compared to that of pure manufacturing companies.

Neely et al. (2011) combined OSIRIS panel data from 2007, 2009, and 2011. Their regression results showed that there was no statistically significant relationship between a company being involved in servitisation and its profitability or current firm value. Their findings suggest the presence of a servitisation paradox, indicating that servitisation did not have a beneficial effect on companies.

Wang et al. (2015) supported this view, using a meta-analysis to demonstrate that service revenue had no significant impact on company performance. However, they also noted that using service revenue as a measure of the degree of servitisation might have some drawbacks. For example, many manufacturing firms may not differentiate between service revenue and product revenue, and a high proportion of service revenue to total revenue may not represent a high degree of servitisation but could be the result of an unsuccessful product business.

Huikkola et al. (2020) suggested that it is important to consider the impact of servitisation on company boundaries. Based on case studies of four multinational companies in Finland, they showed that servitisation involves a clear redefinition of corporate identity, which in turn affects corporate culture. As a result, service manufacturers need to move closer to the end-user to position themselves as solution providers. It's important to note that servitisation varies across different industries and service products.

Digitization and servitisation

Our research is also related to digitization and servitisation. An increasing amount of literature has begun to explore the impact of digitalisation on the servitisation of firms. With the influence of the information technology revolution, digital technologies further enable the interconnection of customer data, internal data, and external entity data (Favoretto et al., 2019). At the same time, Internet technology has overcome traditional geographical constraints, significantly reducing the time and space distances between locations, and maximizing the integration of different resources. Ardolino et al. (2018) conducted case studies of four different large manufacturing companies (Piaggio, Canon, KONE, and Alpha) to explore the impact of internal digitization on servitisation. Internal digitization within these companies included three types of digital capabilities: IoT (Internet of Things), CC (Cloud Computing), and PA (Predictive Analytics). They found that digitization within firms can drive business innovation, expand service portfolios, and improve service processes, even helping to plan long-term employee development strategies.

Coreynen et al. (2017) conducted case studies on four Belgian small and medium-sized manufacturing enterprises (SMEs). They proposed ways in which digitization supports services, primarily through the use of online self-service management tools that allow customers to complete tasks independently, alongside corresponding customer relationship management.

Martín-Peña et al. (2019) used data from Spain's Business Strategy Survey from 2014 to 2017 to examine the causal relationship between digitalisation and servitisation. They defined digitalisation as the degree of a firm's ICT capital usage, such as information technology programming services, online sales to firms, and online sales to end consumers. Servitisation was measured by the proportion of the firm's sales accounted for by service offerings. Their empirical results indicate that servitisation and digitalisation are positively related to firm performance, with digitalisation positively mediating the relationship between servitisation and firm performance.

Calle et al. (2020) used a logistic regression model to study the relationship between digital capabilities and servitisation in the Spanish industry, using a sample of over 2,000 Spanish manufacturing firms. The measure of digital capabilities was based on whether the firms used software technologies such as CAD, ROB, CNCM, and FMS. Their findings indicated that production combined with digital capabilities, which enable the marketing of products and services over the Internet, significantly influences a firm's capacity for servitisation. Consequently, the development of high digital capabilities geared towards production has a noteworthy impact on a company's ability to offer services.

The impact of local broadband infrastructure was also explored in studies by Chen and Zhang (2021) and Zhao et al. (2022). Chen and Zhang (2021) focused on the impact of financial digitalisation on the servitisation data of Chinese manufacturing listed companies from 2011 to 2018. They used the Digital Financial Index at the city level as a representation of financial digitalisation and Internet penetration rates as an instrumental variable. The study found that the Digital Financial Index significantly promoted manufacturing servitisation, with a marginal contribution rate of 0.10%, indicating that the construction of external digital information networks positively enhances the manufacturing capabilities of firms.

Zhao et al. (2022) conducted a study using a spatial econometric model to investigate the impact of the digital economy on industrial structure upgrading in 237 prefecture-level cities in China from 2011 to 2019. They developed regional digital economy indicators, taking into account factors such as the total number of network users, the number of information technology professionals in the region, total e-commerce sales, and the Digital Financial Index. The study found that the development of the digital economy has a significant positive direct effect on industrial servitisation. Both the Spatial Autoregressive Model (SAR) and the Spatial Durbin Model (SDM) showed that the digital economy has a positive spatial spillover effect on industrial upgrading.

While the existing literature has extensively examined servitisation from the perspectives of theoretical frameworks, firm characteristics, and industry-specific factors (e.g., Crozet and Milet, 2017; Fang et al., 2008; Kohtamäki et al., 2013; Sousa et al., 2017), a critical research gap remains regarding the role of broadband infrastructure as an enabling factor for servitisation in manufacturing firms. Most prior studies have focused on organizational culture, managerial strategies, or general measures of digital capability, but seldom isolate broadband internet access as a distinct driver of servitisation. Moreover, empirical work on this topic is limited and largely concentrated in emerging economies and often uses broad digitalisation indicators that incorporate different digital transformation channels.

My research addresses this gap by being the first to exploit the staggered rollout of broadband infrastructure in the UK as an exogenous source of variation to study servitisation in manufacturing firms. This approach highlights broadband access as a distinct and measurable driver of firms' transition from product-oriented to service-oriented business models. Unlike previous studies that focus primarily on internal firm decisions or organizational strategies, my findings show that external digital infrastructure, in particular broadband availability, plays a significant role in facilitating servitisation. The results indicate that firms' service transformation can be shaped as much by changes in the external digital environment as by internal choices.

3.5 Broadband infrastructure endogenous problem

One strand is also related to endogenous problems and identification methods of testing the effect of the Internet and ICT.

The identification of causal effects between broadband infrastructure and economic outcomes faces significant methodological challenges, primarily due to endogeneity. Firms and individuals might proactively adopt broadband technologies to gain competitive advantages, and unobservable factors such as regional economic conditions can simultaneously influence broadband adoption and economic outcomes (Fabio, 2023). Consequently, robust causal identification strategies are essential to overcoming these endogeneity issues.

One common approach involves exploiting exogenous variation related to physical broadband infrastructure constraints. A significant strand of literature leverages the physical characteristics of ADSL technology, particularly the inverse relationship between internet speed and distance from broadband infrastructure. Czernich (2012), Gürtzgen et al. (2021), Billari et al. (2018, 2019), and Donati et al. (2022) all used variations in municipality distance to broadband exchanges as instrumental variables (IV) for broadband availability. Specifically, Czernich (2012) and Gürtzgen et al. (2021) employed Two-Stage Least Squares (TSLS) models using municipality distance to nearest distribution frames to identify the impact of broadband penetration on voter participation and employment rates, respectively. Billari et al. (2018, 2019) similarly defined binary instrumental variables based on a threshold distance, examining the influence of broadband on sleep duration, satisfaction, and fertility decisions.

Other studies extend this approach: Donati et al. (2022) used distance to advanced exchanges in Italy as an instrument, finding broadband increased mental health issues among adolescents. Cambini et al. (2022) measured broadband availability by whether municipalities were within 10 km of Optical Line Terminals, showing ultra-fast broadband negatively impacted eighth-grade student performance, particularly among boys, but had no significant effect on younger students. These studies consistently highlight distance as a credible source of exogenous variation in broadband speeds to address endogeneity.

Broadband rollout often proceeds in phases due to policy constraints, funding limitations, geography, and technological hurdles, generating temporal and spatial variation suitable for quasi-experimental designs like difference-in-differences (DiD).

Campante et al. (2018) leveraged Italy's staggered ADSL rollout from 1996–2013, using distance from each municipality to the nearest Urban Group Stage (UGS) and a post-2001 dummy in a DiD model. They found broadband access reduced parliamentary election turnout but increased other political participation. Hjort and Poulsen (2019) used submarine cable landing events across Africa as an exogenous shock to broadband access. Comparing firms and individuals by distance to the backbone network, they showed high-speed Internet increased technology and overall employment. D'Andrea and Limodio (2023) extended this submarine cable approach to study banking in 37 African coastal countries from 2002–2018, finding broadband boosted credit supply by 22%.

For Italy, Canzian et al. (2019) studied ADSL upgrades in Trento Province that raised speeds from 256 kbps to 20 Mbps, using activation years based on when municipalities reached 20% coverage. Their DiD estimates showed higher broadband speeds significantly improved firm revenues and productivity, with growing effects over time.

The recent studies exemplify the growing use of quasi-experimental designs exploiting staggered or policy-driven broadband interventions to identify causal effects on various economic and social outcomes. Zuo (2021) implemented a triple-difference approach around Comcast's discounted broadband rollout in the U.S., Braghieri et al. (2022) leveraged the staggered introduction of Facebook across universities, and in China, Wang et al. (2022) and Zhang et al. (2022) utilized the "Broadband China" policy as a natural experiment.

Some studies illustrate how combining staggered broadband or mobile Internet rollouts with instrumental variables can further strengthen causal identification in difference-in-differences frameworks. Guriev et al. (2020) use global 3G deployment staggered across countries and instrument with lightning strike frequency to address endogeneity in estimating effects on government approval, while Dodlova et al. (2023) and Donati (2023) similarly exploit 3G expansion in Uganda and South Africa, respectively, instrumenting with geographic or environmental factors. Bessone et al. (2022) leverage within-city variation in Brazilian 3G coverage to link social media exposure to political behaviour. Beyond staggered DIDs, several studies focus on constructing exogenous broadband penetration indices to address endogeneity concerns inherent in broadband adoption. Akerman et al. (2015,2022) advanced this method by combining firm broadband adoption data with municipal-level broadband availability in Norway.

Due to our focus on the expansion of ADSL in the UK, a substantial body of literature has examined various outcomes within this context. De Stefano et al. (2018) and Kneller and Timmis (2016) leveraged activation timing and postcode-level distances as instruments for ICT capital availability; Ahlfeldt et al. (2017) and Flack et al. (2014) applied spatial discontinuity designs around Local Exchange (LE) catchment areas; Faber et al. (2015) and Amaral-Garcia et al. (2022) exploited quasi-random broadband variation across small-area boundaries in regression discontinuity frameworks; while Geraci et al. (2022) and Gavazza et al. (2019)

combined broadband rollout with external instruments such as policy shifts or weather shocks to study broader social and political outcomes. Together, these methods underscore the versatility of using geographically and temporally staggered broadband infrastructure, as well as quasi-exogenous variation, to credibly estimate broadband's causal impacts across diverse economic and social dimensions.

The methodology of our study builds on Malgouyres et al. (2021) and Bergeaud et al. (2021), who exploited staggered regional broadband rollouts to identify broadband's economic effects using difference-in-differences (DID) frameworks. Malgouyres et al. (2021) defined the year with the largest broadband penetration increase as the treatment event in their staggered DID and event-study design, demonstrating that broadband access significantly raised firm imports over time. In contrast, Bergeaud et al. (2021) used the initial year of broadband availability as the event time to capture the earliest impacts of broadband diffusion, finding evidence of a technological bias that favoured high-skilled employment and increased domestic outsourcing. Building directly on this approach, our study first constructs a regional broadband index for UK local exchange areas, then defining policy start times for each district to implement a staggered DID design. Unlike Akerman et al. (2015, 2022), who relied on household survey data for broadband penetration, our index is derived from the timing and scope of local exchange activations, determined by factors such as engineering team availability, and historical network layouts, which are exogenous to local economic conditions. Unlike De Stefano et al. (2018) and Kneller and Timmis (2016), who rely primarily on point-to-point distance measures to capture broadband availability, our study develops a comprehensive regional broadband index that aggregates exogenous variation at the district level. This index provides a broader, more flexible tool for analysing broadband's economic impacts across different sectors and outcomes, thereby enhancing both the external validity and the policy relevance of the empirical analysis. And by explicitly restricting our analysis to periods when broadband rollout was exogenous to regional demand (before 2002), we achieve a cleaner identification of broadband's causal effects on firm outcomes, while our staggered DID model serves as a robustness check to ensure the validity of our findings.

3.6 Conclusion

In summary, this study advances literature on broadband and firm dynamics by integrating evidence across entry and exit patterns, performance outcomes, and servitisation processes, while addressing key identification challenges. By positioning broadband infrastructure as a critical external driver of firm behaviour, we move beyond the traditional focus on internal managerial strategies or general ICT adoption. The findings show that broadband infrastructure has heterogeneous effects: it can accelerate firm exits and constrain new firm formation in some sectors, while boosting employment and revenues in others. These results challenge the prevailing assumption that broadband straightforwardly promotes entrepreneurship. Moreover, by identifying broadband as a distinct enabler of servitisation in manufacturing, this research highlights the infrastructural foundations necessary for transitions to service-oriented business models. This dimension has been largely overlooked in the existing servitisation literature.

Methodologically, the study develops a robust identification strategy by exploiting quasi-exogenous variation in broadband activation timing to construct a regional broadband index. This approach provides clearer causal estimates than many existing studies that rely on measures of internal broadband adoption.

Chapter Four Broadband Infrastructure and Firm Entry and Exit

4.1 Introduction

The purpose of this chapter is to measure the impact of broadband infrastructure development on the entry and exit of local businesses. We exploit a quasi-natural experiment arising from the context of the UK's broadband rollout from 1998 to 2002. Our analysis estimates the effects of regional broadband infrastructure development on business entry and exit across districts. We then explore how these effects vary across industries.

Infrastructure has traditionally been regarded as a crucial driver of economic development. Large-scale infrastructure projects, such as highways, railways, and airports, are believed to induce environmental changes that can either stimulate entrepreneurial activity or contribute to the establishment and dissolution of enterprises. The increasing availability of extensive micro-level data has further facilitated rigorous investigations into causal effects, as demonstrated by studies on U.S. transportation systems (Small and Verhoef, 2007), European highway networks (Percoco, 2016; Holl, 2016), and China's high-speed rail system (Chen and Haynes, 2017). Since the early 2000s, governments globally have actively promoted the development of so-called Digital Highways, supported by substantial subsidies. For example, the UK government introduced policies like "The Broadband Future" (2002) and "Ultra-Fast Broadband in the UK" (2014). Governments posit that broadband infrastructure development can extend economic growth to underserved regions, rather than merely enhancing the provision of public services such as education and healthcare.

Although the expansion of broadband access is often regarded as a key economic development strategy, the impact of broadband infrastructure development on the creation and dissolution of local businesses has been relatively understudied in academic research. This remains a significantly underexplored area of research, as the environmental changes induced by digital infrastructure development can shape the behaviour of both incumbent and entrant firms within a region. Traditionally, investments in infrastructure have been associated with environmental shifts that can either foster or inhibit economic activities, with the construction of information networks likely to further accelerate these changes. A substantial body of theoretical research suggests that information technology enhances productivity and reduces production costs by lowering the costs associated with search, replication, transportation, tracking, and verification (Bloom et al., 2012; Goldfarb and Tucker, 2019). Broadband services have the potential to expand the sales reach of existing businesses, as the communication cost difference between nearby and distant locations is nearly negligible. Additionally, consumers purchasing physical goods online can overcome the transportation costs associated with carrying these goods, which similarly benefits remote startups (Pozzi, 2013). Although broadband infrastructure is highly capital-intensive, it is expected to help reduce barriers to entrepreneurship by enhancing connectivity, interaction, and the exchange of knowledge and ideas, thereby potentially fostering the development of entrepreneurial ventures (Kolko, 2012; Ghio et al., 2014). On the other hand, broadband enables remote companies to access more distant markets, identify cheaper or more reliable suppliers, and more easily acquire new technologies and ideas, thereby intensifying market competition. This dynamic is evident in the success of online sales, which has led to a reduction in offline sales (Choi and Bell, 2011). For example, online media consumption has increasingly replaced traditional offline media consumption (Wallsten, 2013). These changes may alter the distribution of businesses or lead to the exit of firms in certain industries. In summary, the net impact of broadband infrastructure on businesses could be either positive or negative.

Empirical research on this topic has often yielded controversial results. Previous studies have explored how access to broadband services influences business entry, but the evidence is predominantly based on data from the United States, with limited studies focusing on Europe and developing countries. For instance, the introduction of ADSL in the United States has been linked to an increase in business startups (Holt and Jamison, 2009), and in Africa, broadband access has led to an increase in the number of businesses participating in trade. (Hjort and Poulsen, 2019). However, even within the United States, the impact of broadband networks on business entry and exit varies across regions. Van Gaasbeck et al. (2009) found that broadband access in California had no significant effect on business entry.

Moreover, the literature lacks sufficient analysis of the impact of limited broadband access on business exits and the net number of businesses, thereby overlooking the potentially differing effects of broadband access on start-ups and incumbent firms. Only a small number of studies examine firm exits directly. Chen et al. (2023) find that broadband reduces business exits in the United States, while research in Europe has found the opposite effect (Cambini and Lorien, 2023). Building on this literature, our study examines the effects of broadband on business exits and the net number of businesses, alongside business entry.

The primary research questions of this chapter are as follows:

Hypothesis 1: Broadband infrastructure is positively correlated with business market entry. The development of broadband infrastructure reduces the costs of market entry, resulting in an increase in new businesses entering the market.

Hypothesis 2: Broadband infrastructure is positively correlated with business market exit. Investments in broadband infrastructure may simultaneously exert a disruptive effect, shifting economic activities from local to online markets, thereby impacting some of the existing businesses in these areas. This shift manifests as the exit of existing firms from the market.

Although many studies have examined the impact of broadband on business market entry, there has been limited attention to the heterogeneous effects of broadband access on business exits across different industries. Varying levels of dependence on information infrastructure among sectors lead to different market responses to new broadband developments. For example, in the software industry, the rapid acquisition of information, new ideas, and innovative methods is critical. Therefore, infrastructure like broadband is expected to be particularly beneficial for entrepreneurial activities in environments such as the software industry. Hence, we propose:

Hypothesis 3: Broadband infrastructure has heterogeneous effects on businesses across different industries.

In this chapter, we employ the two-way fixed effect (TWFE) model to perform baseline regressions on local business entry and exit. The gradual deployment of broadband Internet in the UK, due to engineering constraints and BT internal decision, was carried out in stages over several years. In certain phases, the primary objective was to maximise population coverage within specific regions. We leverage this phased rollout of broadband in the UK between 1998 and 2002 as a quasi-natural experiment, employing a staggered difference-in-differences framework as a robustness check to estimate the causal effect. For the data, we compile a district-level panel on broadband availability from 1997 to 2002 and construct an indicator of broadband penetration (or treatment status) at the district level. This indicator is then merged with district-level business activity from Value Added Tax (VAT) registrations.

Our findings reveal that, on average, broadband infrastructure increases business exits while reducing business entry. In our baseline regressions, we observe a clear rise in firm exits, whereas the decline in entries is less pronounced. However, once we apply an event-study framework, broadband adoption is shown to have significant effects on both margins: two years after activation, firm entry decreases by about 6.5%, while firm exit increases by roughly 5%. Several robustness checks using alternative dynamic specifications yield consistent results, reinforcing the conclusion that broadband rollout exerts a substantial impact on firm dynamics.

Evidence from manufacturing suggests that firms experience rising exit rates and a contraction in firm stock, reflecting intensified competition and market consolidation. This implies that the baseline results are likely driven by manufacturing. By comparison, service-oriented section, including education, finance, public services, tend to benefit more strongly, with broadband access associated with lower exit rates or increases in firm stock. These patterns highlight that the impact of broadband depends on sectoral characteristics such as digital intensity, customer interface, and the ability to integrate new technologies into existing operations.

The following of this chapter is organised as follows: Section 4.2 introduces the dataset and lists variables from the built panel database, displays the summary statistics of variables; Section 4.3 introduces the simple model we followed, and introduces the applied empirical strategy explains the using of TWFE approach and presents adjustments and controls in the model specifications; Section 4.4 lists the findings, such as the impacts of local broadband access, robustness check and heterogeneity analysis in in sector; Section 4.5 is the conclusion section highlighting the main findings and policy implications.

4.2 Data

In this section, in order to explore the causal effect of broadband access on firm entry and exit and test our three hypotheses: (1) Broadband infrastructure is positively correlated with firm entry. (2) Broadband infrastructure is positively correlated with firm exit. (3) Broadband infrastructure has heterogeneous impacts on firms across different sectors. We combine three main sources of information: a district-level dataset on firm entry and exit, a unique district-level broadband Internet availability[5], and district-level economic information. We provide a description of our data in the following subsections.

Dependent variable

We measure firm entry and exit using the VAT (Value Added Tax) registrations and deregistrations dataset from Nomis (nomisweb.co.uk), which is an official labour market statistics portal provided by ONS. VAT registration contains official estimates of the number of businesses registering and de-registering for VAT as published by the Department for Business, Enterprise and Regulatory Reform (BERR). VAT registration/De-registrations VAT (Value Added Tax) is a tax added to most products and services sold by VAT-registered businesses. Businesses are required to register for VAT if their VAT-taxable turnover exceeds the £60,000 threshold. Some businesses do voluntarily register for VAT even though their turnover is below the threshold.[6]

[5] We already discussed the details about how we build the broadband internet availability in background section 2.

[6] And 1.9 million of the estimated 4.5 million enterprises in the UK were VAT-registered in 2006. Data for 2006 shows that around a fifth of all registrations have turnover below the VAT threshold. (https://www.nomisweb.co.uk/articles/338.aspx)

VAT registration is the best official guide to the pattern of business start-ups and closures. The VAT registration data used in this study are aggregated at the district-year level and do not contain micro-level information on individual firms' decisions to register or deregister. As such, the data provide a regional overview of firm births and deaths but do not allow for tracking firm-specific behaviours or characteristics.

VAT dataset provides four variables:

Registrations. The number of enterprises registering for VAT each year. This is an indicator of the number of business start-ups. It excludes most of the very smallest one-person businesses.

Deregistrations. The number of businesses de-registering from VAT each year. This is an indicator of the number of closures. Businesses deregistering from VAT do so due to closure, or (in a minority of cases) because turnover has fallen below the registration threshold. Closure does not necessarily involve bankruptcy or insolvency proceedings, which make up only around one in four closures.

Stock at end of year. The number of enterprises registered for VAT at the end of the year. This is an indicator of the size of the business population. Since the vast majority of VAT-registered enterprises employ fewer than 50 people, it is also an indicator of the small business population.

Net change. Net gain or loss in the stock of registered enterprises each year - equal to registrations less deregistration. For each variable, the data is aggregated at the industry (section) level and the location (district) level.

There are still several restrictive factors related to VAT that could affect the validity of our research. First, many small enterprises voluntarily register with VAT, which may lead to under-estimate the total number of starts and closures. Second, VAT only provides aggregated data -sections level from Standard Industrial Classification 1992(SIC92), which prevents us from examining more detailed classification indicators, such as 2-digit and 4-digit levels. Additionally, since the SIC92 classification is not effective for further subdividing ICT-related industries, which were better categorized starting with SIC2003.

VAT provides the section aggregation level information for industry classification. According to SIC92 classification, VAT provide 11 sections: Agriculture; Forestry and fishing (SIC A,B) Mining and quarrying; Electricity, gas and water supply (SIC C,E); Manufacturing (SIC D); Construction (SIC F); Wholesale, retail and repairs (SIC G); Hotels and restaurants (SIC H); Transport, storage and communication (SIC I); Financial intermediation (SIC J); Real Estate, renting and business activities (SIC K); Public administration; Other community, social and personal services (SIC L,O); Education; health and social work (SIC M,N). It is worth mentioning that SIC92 grouped commercial activities, the computer industry, research and development, and real estate activities together under SIC K. Additionally, industries related to ADSL infrastructure, including the sector where BT (British Telecommunications) operates, were grouped together with transportation under SIC I.

Table 4.2.1 reports the average number of VAT-registered enterprises by year and industry section, based on aggregated district-level firm counts. The values are calculated as the average number of registered firms across all districts, and reflect firms that were registered for VAT and actively operating at the end of each year. SIC K accounts for around for 25% - 30% of the total stock, as it includes real estate activities, renting of machinery and equipment without operator and of personal and household goods, computer and related activities, research and development, and other business activities. At the same time, there are only a limited number of mining-related companies in the UK, with an average of 4.1 per district. Table 4.2.1 shows that the majority of sectors have experienced growth over the past 10 years, except for Manufacturing and Agriculture, which have experienced a decline.

Table 4.2.1 List the stock of registration by year and section

Section/Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1 : Agriculture; Forestry and fishing (SIC A,B)	344.6	340.8	337.3	333.7	330.7	329.2	327.5	326.4	326.3	324.8	320.9
2 : Mining and quarrying; Electricity, gas and water supply (SIC C,E)	4.0	4.0	4.0	4.1	4.2	4.2	4.1	4.2	4.2	4.1	4.3
3 : Manufacturing (SIC D)	409.7	409.4	407.6	407.0	403.1	396.8	392.7	387.0	382.7	377.8	376.6
4 : Construction (SIC F)	445.3	453.3	460.5	469.3	480.1	492.4	511.8	529.4	549.2	567.8	590.6
5 : Wholesale, retail and repairs (SIC G)	980.5	973.3	967.9	963.4	952.5	947.0	953.4	958.7	968.0	975.5	986.4
6 : Hotels and restaurants (SIC H)	275.9	279.8	285.9	293.8	303.1	311.0	321.6	330.1	339.5	347.7	357.1
7 : Transport, storage and communication (SIC I)	177.4	180.9	183.7	187.0	189.4	191.5	194.4	198.7	203.2	206.5	210.6
8 : Financial intermediation (SIC J)	43.8	45.2	47.0	49.0	50.3	51.0	52.0	53.0	54.4	55.0	55.6
9 : Real Estate, renting and business activities (SIC K)	1033.2	1124.0	1191.1	1244.8	1282.6	1318.1	1370.2	1421.7	1476.3	1530.9	1629.1
10 : Public administration; Other community, social and personal services (SIC L,O)	332.3	337.5	342.9	349.0	356.2	362.5	366.2	365.6	366.4	369.5	370.9
11 : Education; health and social work (SIC M,N)	59.0	60.1	62.1	64.1	66.2	67.3	70.0	72.2	74.4	77.2	81.4
All section	4105.6	4208.3	4290.0	4365.2	4418.5	4470.9	4564.0	4647.0	4744.5	4836.9	4983.6

Note: This table shows the stock of VAT-registered enterprises by industry section and year. The figures represent the mean number of active VAT-registered firms at the district level, aggregated by 11 SIC92 sections. The stock refers to firms registered and operating at the end of each calendar year.

Independent Variable

Our broadband data is derived from two main sources. The first one comes from Samknow.com. It is authorised by Ofcom, the regulatory authority for the UK's telecommunications industry. It provides the local exchange ADSL activation time and year, so that we have information on the diffusion of ADSL around the UK. Moreover, we derive the boundary and location for each local exchange from Point-topic.com. It not only provided the coverage area of each local exchange but also the linear distance and loop line length from each residential/commercial postcode in the UK to the corresponding local exchange. We merge two of dataset to create the district level broadband access/penetration index. However, it's important to note that the Ofcom data does not cover the Hull area, which is their own independent ADSL operator, KCOM. At the same time, the coverage of the local exchange does not completely coincide with the administrative boundaries. Lower-level administrative divisions such as wards and parishes have boundaries that are difficult to determine, but they align more consistently with the district level. This is the reason we used the method of Malgouyres et al. (2021) to construct the district-level broadband access index Z_{jt} in section 2.3.

The broadband access index Z_{jt} for each Local Authority/district j is the continuous index of each broadband access in the local authority/district:

$$Z_{jt} = \sum_{b\in j}\left(\frac{number\ of\ days\ with\ activation\ in\ b\ \ since\ Jan\ 1st\ of\ year\ t}{number\ of\ days\ in\ year\ t}\right) \times \underbrace{\frac{area_{\ bt}}{\sum_{b\in j} area_{bt}}}_{A_{bt}} \qquad (2.1)$$

where $b \in j$ represents the area of the local census block (we use lower super output area(LSOA) as our census blocks from UK census 2001) in Local authority/district j . Every Local Authority in the UK is divided into census blocks.

Control Variables

Economic outcome and population size

Areas with higher economic output and greater spatial density tend to have more intense economic activities, fostering the flow of ideas and knowledge and offering more entrepreneurial opportunities. Thus, we included two market size indicators: (i) economic income, measured as the logarithm of GDP per capita, and (ii) population density, defined as the number of people per square mile of land. I obtained per capita income data and population estimates for districts from the ONS, and the area of each region was sourced from the UK Census. These indicators help capture the economic vibrancy and potential for innovation within each district, providing a comprehensive view of the local market strength.

Demographic information

Including demographic variables like education and unemployment rate in regional economic studies is essential for controlling confounding factors, leading to more accurate and comprehensive insights into local economic performance. So, we collect information about the higher education ratio and unemployment rate from the 1991 Census. The variable "EDU" measures the proportion of the adult population (aged 18 and over) with higher education qualifications, based on data from the 1991 UK Census 10% sample on educational attainment (Table L84: Qualified Manpower). It is constructed by summing the number of individuals holding Level a (higher degree), Level b (bachelor's degree), and Level c (other higher-level qualifications such as diplomas), and dividing this by the total number of persons aged 18 and over. The unemployment rate is calculated as the share of economically active individuals who were unemployed from the 1991 UK Census 100% sample. Specifically, it is defined as the number of unemployed persons divided by the total economically active population.

In our regression, we will include an interaction term between an initial demographic variable and year in regression analysis to help capture how the effect of demographic variables on the outcome changes over time.

Local market industry agglomeration

The concentration of industries across cities can influence broadband availability, firm profitability, and entry and exit behaviour, reflecting local market characteristics beyond the control of individual firms. Market concentration measures are therefore essential controls: while they can promote firm entry and growth, they may also affect early local broadband adoption. Omitting these factors could introduce upward bias in estimating the impact of broadband on firm entry or profitability.

Industry concentration is measured using the Herfindahl-Hirschman Index (HHI), which is a reverse indicator of local industry diversity, calculated based on data from the Business Register and Employment Survey (BRES)/Annual Business Inquiry (ABI). This survey records the number of jobs held by employees, detailed by sex, full/part-time status, and detailed industry (4-digit SIC) at the employees' workplace location. The dataset includes district-level employment from 1998 to 2008, categorized by the SIC92 industry classification. Despite ABI providing the newer SIC code (SIC03) and more detailed (4-digital level) data, we condensed the values into 11 sections (SIC92) to align with VAT data, ensuring consistency and completeness. We use industry employment numbers to define industry concentration (Chen et al., 2023).

Define the employment share of industry sections s in district $j$and year t by:

$$Share_{jst} = \frac{Employment_{jst}}{Employment_{jt}}$$

The Herfindahl-Hirschman Index in in district $j$and year t is:

$$HHI_{jt} = \sum_{\{s=1\}}^{\{S\}} \left(Share_{jst}\right)^2 \;; S = 11$$

The index ranges in values from 0 to 1, where values closer to one indicate greater industrial concentration.

As a second measure of industrial agglomeration, we construct an industry cluster index CLU_{jst}, defined as the share of enterprises in section s within district j relative to the corresponding national share.

$$CLU_{jst} = \frac{number\ of\ enterprises\ in\ j,s,t}{all\ entreprises\ in\ j,t} / \frac{number\ of\ entreprises\ in\ s,t\ in\ the\ UK}{all\ entreprsises\ in\ t\ in\ the\ UK}$$

Higher-level industry clusters would suggest a locational comparative advantage in section production. When considering the heterogeneous impact of broadband infrastructure on industry section, we include this indicator in our analysis.

In our regression, we also include an interaction term between initial industry variable and year in regression analysis to help capture how the effect of industry variables on the outcome changes over time.

Sample Selection and Summary Statistics

The original VAT data is compiled by industry, district, and year. It includes data on the registration and deregistration of businesses across 11 industry section in 408 districts in the UK. We excluded the agricultural and mining industries, as their entry depends on the presence of necessary natural resources, such as arable land or mineral deposits. Public-related sectors are retained, although profit motives may differ from those in private-sector industries.

We also excluded unclassifiable areas. In 2009, local government structural changes resulted in the merging and splitting of several districts, and new administrative codes replaced older codes. Because the VAT data provide only the pre-2009 codes for years prior to 2009, we cannot harmonise these areas consistently and therefore remove the affected observations. In addition, we exclude Northern Ireland and the Hull area due to broadband data limitations. Our final dataset includes 368 districts, with up to 11 sectors per district. Overall, we have 4048 observations, encompassing 1,812,240 registered businesses and 1,442,005 deregistered businesses from 1997 to 2007. However, due to endogenous periods in the sample (2003 to 2004), our final estimation sample only includes data from 1997 to 2002.

Table 4.2.2 Summary Statistics: Full Sample and Estimation Sample

Full sample(97-07)	Obs	Mean	Std. Dev.	Min	Max
Registration	4048	447.688	388.718	25	5270
De registration	4048	356.227	320.932	25	4175
Stock of registration	4048	4176.986	3201.236	585	42025
Net registration	4048	91.461	100.502	-365	1595
Broadband access index	3680	.507	.441	0	1
HHI	3680	.157	.021	.073	.346
Population	4048	150464.46	103017.93	1908	1029021
year	4048	2002	3.163	1997	2007
Edu rate(1991)	3927	.12	.044	.032	.33
Unemploy rate(1991)	3927	.083	.033	.036	.225
GDPPER	3450	42037.626	315212.29	9467	7372442

Estimation sample(97-02)	Obs	Mean	Std. Dev.	Min	Max
Registration	2208	435.611	387.936	25	5270
De registration	2208	353.954	322.939	25	4175
Stock of registration	2208	3969.611	3057.901	585	37920
Net registration	2208	81.658	100.714	-365	1595
Broadband access index	1840	.179	.303	0	1
HHI	1840	.157	.022	.087	.346
Population	2208	148527.8	101998.53	1908	993650
year	2208	1999.5	1.708	1997	2002
Edu rate(1991)	2142	.12	.044	.032	.33
Unemploy rate(1991)	2142	.083	.033	.036	.225
GDPPER	1725	38816.299	276827.72	9467	5456252

Table 4.2.2 provides the summary statistics of the key variables in the full merged dataset and the estimation sample. On average, each district-level has 447 business registrations per year, while 356 businesses deregister, leading to a slow but steady increase in the overall number of businesses, with a net registration of 91 between 97-02. The broadband access index across all observations is 46% during this full sample period. The Estimation sample shows the

broadband access index is lower full sample, which indicates that our estimation sample is at the early stage of ADSL broadband rollout. But we still can find that some districts already get full ADSL broadband access, max =1.The HHI, education rate (EDU), unemployment rate and GDP per capita have missing values because these indicators are unavailable for some districts.

4.3 Empirical Model

We want to explore the causal effect of Broadband access on firm entry/exits. We first provide the simple model from (Chen, et al., 2023). The model illustrates that if firms' profitability increases with the growth of broadband penetration, it may lead to new firm entries; conversely, if profitability decreases as broadband penetration grows, existing firms might choose to exit the local market. Then, we provide the identification strategy we used and discuss the heterogeneity analysis.

Simple model

According to the Chen et al.,(2023), The representative firm in sector s in district j at time t uses a vector of inputs, x, Local exogenous market attributes, L, and local access to broadband, Z, to produce q units of final good with a production function $q = f_s(x, Z, L)$ The vector Z reflects local market that affect firm costs or revenues such as the availability of local customers or suppliers. The factors may affect firm profitability, but may also be correlated with the presence or absence of broadband services, and so they will need to be controlled in the estimation. Z is the penetration of broadband service at time t so it reflects the availability at the start of period *t*. From the production function, the producer's cost function is

$$C_s(q) = p_x f_s^{-1}(q, Z_{jt}, L) \qquad (1)$$

We assume that $\frac{df_s}{dZ_{jt}} > 0$ so that the producers' productivity can only rise or remain unchanged with access to broadband. Similarly, we assume that $\frac{dp_x}{dZ_{jt}} <$ so that broadband access can only lower or leave unchanged the cost of sourcing inputs.Then,

$$\frac{dC_s}{dZ_{jt}} = \frac{dp_x}{dZ_{jt}} f_s^{-1}(q, Z_{jt}, L) + p_x \frac{df_s^{-1}(q, Z_{jt}, L)}{dZ_{jt}} \leq 0 \qquad (2)$$

This implies that broadband's effect on production costs is non-positive.

Let the firm's profit function be

$$\pi_{sjt} = p_x f_s(q, Z_{jt}, L) - C_s(q) \qquad (3)$$

where p_{sjt} denotes the output price faced by the firm. Differentiating with respect to broadband access yields

$$\frac{d\pi_{sjt}}{dZ_{jt}} = \overbrace{\left\{\frac{dp_x}{dZ_{jt}} f_s\left(q, Z_{jt}, L\right)\right\}}^{\{?\}} + \underbrace{\left\{p\frac{df_s\left(q, Z_{jt}, L\right)}{dZ_{jt}}\right\}}_{\{\geq 0\}} - \overbrace{\left\{\frac{dC_s(q)}{dZ_{jt}}\right\}}^{\{\leq 0\}} \quad (4)$$

The sign of $\frac{d\pi_{sjt}}{dZ_{jt}}$ is ambiguous because the sign of the first term, $\frac{dp_x}{dZ_{jt}} f_s\left(q, Z_{jt}, L\right)$ could be different across industries. Without the Internet, the firm only has local customers. The Internet will bring a non-negative online demand from remote customers purchasing online. However, local customers may switch from local purchases to online competitors. As a result, the demand for the local firm' products could shift inward or outward, and so for the same quantity of goods, the price could increase or decrease when the broadband service penetration increases.

If $\frac{dp_x}{dZ_{jt}} > 0$ When this term is greater than zero, firm profitability increases. Positive profits induce two responses: new firms are more likely to enter the market, while incumbent firms are more likely to remain, leading to higher entry and lower exit rates.

If$\frac{dp_x}{dZ_{jt}} < 0$ When this term is less than zero, firm profitability decreases, leading to lower entry and higher exit rates.

And L represent local market features that the firm cannot control, but that may affect firm profits and the availability of broadband. According to McCoy et al. (2018), these local market features include local market industry agglomeration; we use the Herfindahl-Hirschman Index (HHI) and industry cluster (CLU) as proxies to avoid the unknown bias.

Identification Strategy

We employ a Two-way fixed effect model (TWFE) approach to design model specifications to examine the firm entry/exit and broadband infrastructure. The model specifications are as follows:

$$Y_{jt} = a + \beta Z_{jt} + \sigma \mathrm{X_{jt}} + \; + LA_j + Year_t + \epsilon_{jt} \; (4.1)$$

where Z_{jt} refers to the continuous index form of broadband access index at local authority/district j at time t from equation (2.1) which we built at section 2.3. Y_{jt} represents the firm entry(registration) and firm exits(deregistration). To address the distribution of firm entry or exits counts across districts, we take the natural logarithm of the total number of entries. As a robustness check, we also use the inverse hyperbolic sine transformation. The coefficient β represent the effect of broadband access index on firm entry/exit outcome. $\mathrm{X_{jt}}$ is a vector of district-specific characteristics, including district-level GDP per capita, Herfindahl Hirschman

Index, Population density, local higher education rate and unemployment rate. We use their initial values(Year1998) and interact them with year fixed effects. These pre-existing conditions in each district interact each year to capture local dynamic relationships. LA_j and $Year_t$ respect the district level (Local Authority) fixed effect and year fixed effect respectively. The district fixed effect captures all time-invariant sources of spatial variation, and the year fixed effect captures any time-specific influences that could affect the outcome. The error term ϵ_{jt} cluster at district level.

4.4 Empirical Results

Baseline Results

We present the baseline results in Table. 4.4.1 to Table. 4.4.2. Table.4.4.1 reports the regression results on firm entry. After adding control variables in specification (2), the coefficient declines, remains negative, but becomes insignificant.

In the baseline regressions without controls (Column 1), we observe a significant negative relationship between the broadband access index and firm entry, with a one-unit increase in broadband access associated with a 5.4% decline in entry. This result runs counter to our Hypothesis 1, which predicted a positive effect, and instead suggests that broadband rollout may be linked to stronger competitive pressures or higher entry barriers.

However, once we introduce interactions between initial district-level characteristics and year trends, especially initial GDP per capita, the effect on entry becomes statistically insignificant. This change is consistent with our earlier observation that broadband rollout was correlated with local economic development: wealthier districts were connected earlier. After accounting for these pre-existing district-level differences, the effect of broadband on entry disappears.

Our findings are different from much of the empirical evidence. For instance, Chen et al. (2023) document a positive impact of broadband on firm entry in the United States, while Hjort and Poulsen (2019) report similar results in the African area. At the same time, our results partially support Cambini and Sabatino (2023), who show that broadband reduces entry among medium-sized firms.

Table 4.4.1. Broadband Access and Firm Entry: Fixed-Effects from a District-Year Panel

	(1)	(2)
VARIABLES	**log of firm entry**	**log of firm entry**
Broadband Access Index	-0.0540***	-0.0140
	(0.0116)	(0.0183)
Constant	5.856***	5.644***
	(0.00208)	(0.0665)
Observations	1,840	1,685
R-squared	0.990	0.991
R2_within	0.0194	0.0856
Control	NO	YES
DistrictFE	YES	YES
YearFE	YES	YES
District number	368	337

Notes: Estimates are based on sample period from 1997 to 2002. District and year fixed effects are controlled. Standard errors are in parentheses and clustered at district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Table 4.4.2. presents the regression results for firm exit at the district level. In the baseline specification without controls (Column 1), broadband access is positively and significantly associated with firm exit: a one-unit increase in the broadband access index raises firm exit by 5%. When district-level initial characteristics interacted with year are included (Column 2), the magnitude of the coefficient remains positive and statistically significant, though slightly less precise. This stability across specifications suggests that the positive effect of broadband access on firm exit is not driven by underlying district condition, but rather reflects a robust pattern whereby broadband rollout accelerates the exit of firms.

Table 4.4.2. Broadband Access and Firm Entry: Fixed-Effects from a District-Year Panel

	(1)	(2)
	log of firm Exit	**log of firm Exit**
Broadband Access Index	0.0506***	0.0537**
	(0.0148)	(0.0222)
Constant	5.633***	5.566***
	(0.00265)	(0.0785)
Observations	1,840	1,685
R-squared	0.984	0.985
Control	NO	YES
DistrictFE	YES	YES
YearFE	YES	YES
District number	368	337
R2_within	0.0109	0.0630

Notes: Estimates are based on sample period from 1997 to 2002. District and year fixed effects are controlled. Standard errors are in parentheses and clustered at district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Our findings are consistent with Cambini and Sabatino (2023), who also report an increase in firm exits following broadband rollout. We interpret this outcome as the net effect of two offsetting mechanisms. On the one hand, broadband access expands firms' potential markets and may raise demand and profitability by lowering transaction costs and enabling digital sales channels. On the other hand, it simultaneously heightens competitive pressure by facilitating entry from geographically distant firms and intensifying price competition. The loss of local market power and the squeeze on profit margins hit smaller and less productive firms. These firms often lack the scale, efficiency, or digital capability to compete effectively, so they are more likely to shut down. As a result, broadband access leads to higher overall exit rates.

Robustness check

In this session, we conduct four robustness checks. First, we further explore the effect of stock of register firm and net change of firms. Then, we employ an alternative measurement by using the inverse hyperbolic sine function in place of the logarithmic form for the dependent variable. Then we extend our sample period to the full duration, acknowledging the endogeneity issue, to examine the long-term relationship. Finally, we use our DID framework to further explore the casual relationship. And we also use the PPML (Poisson Pseudo-Maximum Likelihood Estimator) method to assess the impact by comparing districts with and without broadband access and in our appendix.

Firm Stock at end of year and net entry

Because registrations and deregistrations fluctuate from year to year, we also examine the end-of-year stock of registered firms and net change to better capture broader trends in business activity and the net balance between entry and exit.

Table 4.4.3. The impact of broadband on Stock at end of year and net entry number

	(1)	(2)
	log of firm Stock	log of firm net change
Broadband Access Index	-0.00550	-0.402***
	(0.00584)	(0.144)
Constant	8.148***	2.044***
	(0.0285)	(0.736)
Observations	1,685	1,553
R-squared	0.999	0.671
Control	YES	YES
DistrictFE	YES	YES
YearFE	YES	YES
District number	337	334
R2_within	0.0572	0.110

Notes: Estimates are based on sample period from 1997 to 2002.District and year fixed effects are controlled. Standard errors are in parentheses and clustered at district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Table 4.4.3. present the results of the stock at end of year and net entry, the results already add the control variables. From column 1, it can be seen that broadband does not have a significant impact on the end-of-year number of firm registrations. Although the coefficient is positive but the estimate is around 0 and insignificant. However, columns 2 show a negative effect broadband access on the net number of entries. Specifically, column 2 indicates that for every unit increase in broadband, net entries decrease by 40%. The observation number in Column 2 decreases because some negative and zero values are missing after the log transfer. As such, the estimation only includes observations with strictly positive net entry values. Therefore, the effect on regions experiencing net firm decline (i.e., more exits than entries) is not captured in this specification, we further test this results using inverse hyperbolic sine function in next section. Overall, the annual total stock number of registered firms has not been affected by broadband access. And the net number of firms entering the market has

decreased, reflecting that firms tend to exit the market rather than enter it in response to the impact of broadband access.

Alternative measurement

We use the inverse hyperbolic sine function instead of the log form. Using the inverse hyperbolic sine function in regression analysis allows for handling zero and negative values, unlike the logarithmic transformation, which requires positive values. Additionally, the IHS transformation can stabilize variance and make the data distribution more normal, leading to more robust and reliable regression models.

Table 4.4.4. The impact of broadband on firm entry/exits/ Stock at end of year/net entry(asinh)

	(1)	(2)	(3)	(4)
	asinh _Entry	**asinh_ Exit**	**asinh_Stock**	**asinh_Net Entry**
Broadband Access Index	-0.0140	0.0537**	-0.00550	-0.629
	(0.0183)	(0.0222)	(0.00584)	(0.520)
Constant	6.337***	6.260***	8.841***	4.164
	(0.0665)	(0.0785)	(0.0285)	(2.654)
Observations	1,685	1,685	1,685	1,685
R-squared	0.991	0.985	0.999	0.489
Control	YES	YES	YES	YES
DistrictFE	YES	YES	YES	YES
YearFE	YES	YES	YES	YES
District number	337	337	337	337
R2_within	0.0856	0.0630	0.0572	0.0523

Notes: Estimates are based on sample period from 1997 to 2002.District and year fixed effects are controlled. Standard errors are in parentheses and clustered at district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Table 4.4.4. presents the results when we include control variables in firm entry/exits. Bellemare and Wichman (2020) demonstrate that the estimates of the inverse hyperbolic sine function can be interpreted similarly to a standard logarithmic dependent variable. Column (1) shows that when the broadband access index has insignificant effect on firm entry. Column (2) indicates that a one-unit increase in the broadband access index results in a significant 5.37% increase in firm exits. These results are consistent with the baseline regression. Column (3)

reveals that broadband access does not have a significant effect on the stock number of firms. Finally, Column (4) indicates does not have a significant effect on the stock number of firms.

Table 4.4.6. Full sample period 1998-2007.

	(1)	(2)	(3)	(4)
	Log of Entry	Log of Exit	Log of Stock	Log of Net Entry
Broadband Access Index	-0.0440***	0.0383***	0.00146	-0.439***
	(0.0143)	(0.0147)	(0.00340)	(0.103)
Constant	6.139***	5.617***	8.303***	5.118***
	(0.183)	(0.0935)	(0.0616)	(0.685)
Observations	3,370	3,370	3,370	3,200
R-squared	0.984	0.983	0.998	0.637
Control	YES	YES	YES	YES
DistrictFE	YES	YES	YES	YES
YearFE	YES	YES	YES	YES
District number	337	337	337	337
R2_within	0.0926	0.0700	0.0461	0.106

Notes: Estimates are based on sample period from 1998 to 2007. District and year fixed effects are controlled. Standard errors are in parentheses and clustered at the district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Extended sample period

Table 4.4.6 presents results from an extended sample period (1998–2007) and reveals a clear asymmetry in the effect of broadband access on firm dynamics. Broadband availability is associated with a 4.4% decrease in firm entry and a 3.8% increase in firm exit, both significant at the 1% level. And the net entry rate declines sharply, while the stock of active firms remains unchanged.

Compared with our baseline sample period, the effect of broadband access on firm entry becomes significant; however, firm exits are reduced. These findings suggest that broadband rollout did not lead to an expansion in the number of firms, but instead restructured the market by accelerating firm entry and exits. This pattern supports the argument that broadband imposes both entry deterrents and competitive pressures, leading to higher exit among less productive incumbents and reduced incentives for new entrants.

Difference in Difference Framework Analysis

To estimate the causal effect of broadband access on firm dynamics, we adopt a difference-in-differences (DiD) strategy that exploits the staggered rollout of ADSL broadband across UK districts between 1999 and 2002. As we discussed in Chapter 2, we treat this rollout as quasi-natural experimental, conditional on pre-determined district characteristics.

The model specifications are as follows:

Traditional DiD Model:

$$Y_{jt} = a + \beta Treated_{jt} + \sigma X_{jt} + LA_j + Year_t + \epsilon_{jt} (4.2)$$

Where Y_{ijt}represents an outcome variables, such as firm entry/exits in year t in district(Local Authority) LA_j . $Treated_{ijt}$ is an indicator for whether in year t, ADSL Broadband was activated at LA_j. X_{jt} are vector for District(LA) level controls. LA_j and $Year_t$ respect the district level (Local Authority) fixed effect and year fixed effect respectively. The district fixed effect captures all time-invariant sources of spatial variation, and the year fixed effect captures any time-specific influences that could affect the outcome. The error term ϵ_{jt} cluster at district level.

Event-Study model:

$$Y_{jt} = \sum_{d=-3}^{d=-1} \beta_d \times 1(t = d + t_{j0}) + \sum_{d=0}^{d=2} \beta_d \times 1(t = d + t_{j0}) + \sigma X_{jt} + LA_j + Year_t + \epsilon_{jt} \quad (4.3)$$

Where t_{j0} represent the year district experience ADSL treatment and term d represent the number of years away from ADSL broadband access treatment year. If d is negative, which means d years before the treatment year, if d is positive, it shows the d year after treatment year. We include a vector of 3 leads and 2 lags of broadband access which range from 3 periods before broadband access until 2 periods after broadband access. β_d represent the effect of broadband access/activation on firm entry/exits, d years away from broadband access/activation and it is the main coefficient of our interest.

Difference in Difference Framework results

Table 4.4.7 reports the results from a traditional DID model. The results show that broadband availability has no significant effect on the log of firm entry (Column 1), log of firm exit (Column 2) firm stock (Column 3), or net entry (Column 4). These findings suggest that, in the short run, broadband expansion did not have a strong impact on firm dynamics when analyzed using a standard DiD framework.

Overall, these estimates motivate the need to consider alternative specifications (event study) or heterogeneous treatment effect models to better capture the dynamic effects of broadband rollout on different aspects of firm behaviour.

Table 4.4.7. The impact of broadband on traditional difference in difference model

	(1)	(2)	(3)	(4)
	Log of Entry	Log of Exit	Log of Stock	Log of Net Entry
Treated	-0.000810	0.0164	-0.00248	-0.0810
	(0.0104)	(0.0121)	(0.00343)	(0.0858)
Constant	5.632***	5.599***	8.145***	1.749**
	(0.0663)	(0.0769)	(0.0285)	(0.716)
Observations	1,685	1,685	1,685	1,553
R-squared	0.991	0.985	0.999	0.668
Control	YES	YES	YES	YES
DistrictFE	YES	YES	YES	YES
YearFE	YES	YES	YES	YES
District number	337	337	337	334
R2_within	0.0851	0.0590	0.0564	0.104

Notes: Estimates are based on sample period from 1997 to 2002. District and year fixed effects are controlled. Standard errors are in parentheses and clustered at the district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

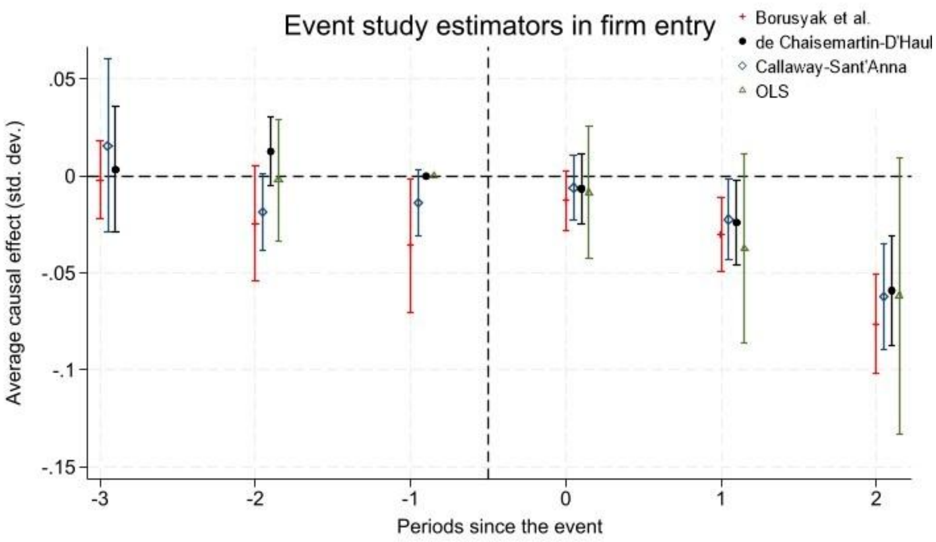
Event-Study Results

In this section, we present the event-study results on firm entry and firm exits. Figure 4.4.8 and Figure 4.4.9 provides the event-study coefficient plot in four methods with different outcome variables.

The coefficients before the treatment are close to zero and insignificant, supporting the parallel trends assumption. However, for t = -1, the Borisyak estimator shows a small negative and marginally significant coefficient, which may suggest mild anticipation effects or slight violations of parallel trends shortly before treatment.

The most notable finding emerges at t = 2, our event study estimates suggest that two years after broadband expansion, new firm entry declines by around 6%, as captured by all three robust DiD estimators. This delayed but significant negative effect implies that broadband access reduces new firm formation.

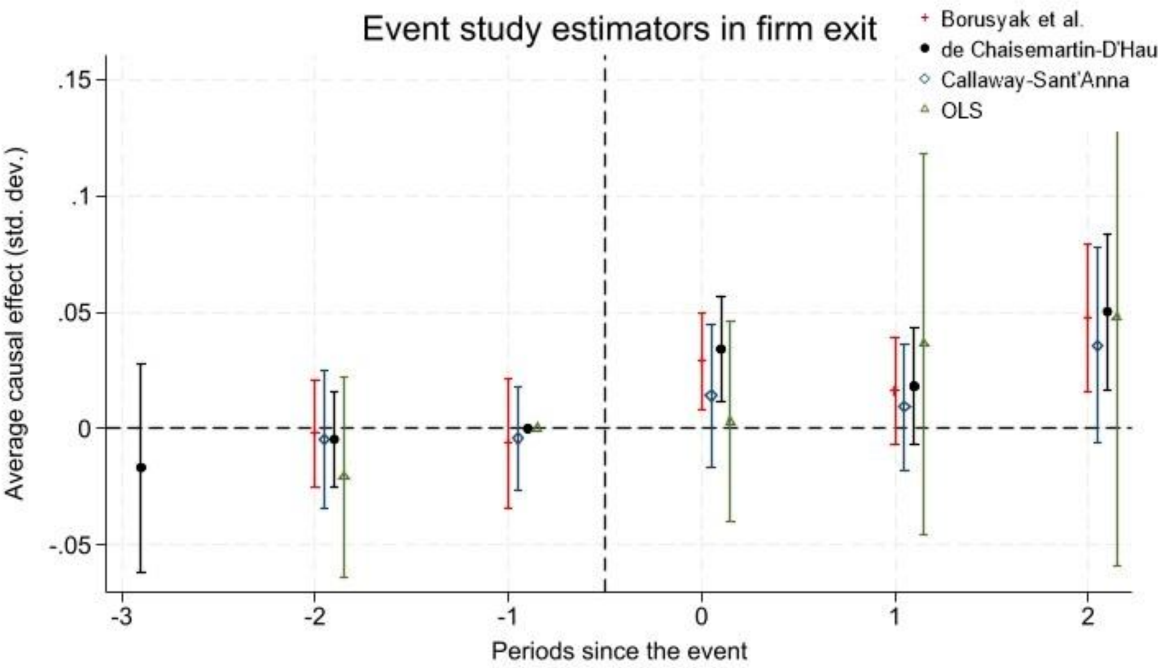
Figure 4.4.8 Event study effects of ADSL Broadband on firm entry



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The time variable is the year and the treatment group variable is given by the year the district activated ADSL technology. Due to the limited sample period (only five periods) and potential bias in estimating heterogeneous dynamic treatment effects, the figure only displays two post-periods to ensure robust estimation. Robust method only controls the local gdpper condition. The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

In contrast, the event study estimates for firm exit show no significant pre-treatment trends, again lending support to the parallel trends assumption. Post-treatment, all estimators suggest a modest upward trend in firm exit, especially at t=2. Both Borusyak et al. and de Chaisemartin–D'Haultfoeuille estimators indicate that firm exits increase by approximately 5% two years after broadband expansion. However, the Callaway–Sant'Anna and OLS estimates remain insignificant, with wide confidence intervals, suggesting a higher degree of uncertainty around the magnitude and robustness of the effect.

Figure 4.4.9 Event study effects of ADSL Broadband on firm exits



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The time variable is the year and the treatment group variable is given by the year the district activated ADSL technology. Due to the limited sample period (only five periods) and potential bias in estimating heterogeneous dynamic treatment effects, the figure only displays two post-periods to ensure robust estimation. Robust method only controls the local gdpper condition. The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

To sum up, we find that broadband access reduces new firm entry while simultaneously increasing firm exit, with both effects becoming more pronounced over time. These trends are especially significant two years after the treatment, suggesting that the impact of digital infrastructure unfolds gradually. The decline in firm entry may reflect mechanisms such as: Market consolidation, where early adopters strengthen their position and deter new entrants; Increased entry barriers, especially for firms lacking digital capabilities. Meanwhile, the rise in firm exits may be driven by greater competitive pressure from digitally enabled incumbents, which squeezes out less productive or non-digital firms, and reallocation effects, whereby digital infrastructure accelerates the exit of inefficient businesses.

Heterogeneity Analysis

Due to industry heterogeneity, we further extended the model to account for the varying entry and exit patterns across different industries within the district. This extension allows us to better understand how industry-specific factors influence the dynamics of business formation and closure, providing a more nuanced analysis of the impact of broadband infrastructure on local economies.

The model specifications are as follows:

$$Y_{jst} = a + \beta_1 Z_{jt} + \beta_2 Z_{jt} \times Industry_{s} + \sigma X_{jt} + CLU_{jst} + \text{Industry}_{s} + LA_j + Year_t + \epsilon_{jst} \quad (4.4)$$

Now, Y_{jst} is our outcome variable at industry section s at district j at year t. In this regression, we add one more control variable, the industry cluster index CLU_{jst} to further capture the industry section level specific agglomeration effect. We use an interaction term for an industry indicator and interact with the Z_{jt} to estimate the differential effect. The coefficient β_2 on the interaction term captures how the effect of broadband on firm entry differs across industries. A positive and significant β_2 for a given industry indicates that broadband access is more strongly associated with firm entry in that sector compared to the omitted (baseline) industry. Industry/Sector fixed effects control for time-invariant differences across industries, recognising that entry and exit dynamics vary systematically by industry.

Heterogeneity Results

The question we attempt to answer in this section is whether industrial section are related to the extent to which firms benefit from broadband accessibility. In this section, we provide the evidence about the firm industry heterogeneity.

Table 4.4.10 presents the estimated effects of broadband access on log of firm entry, firm exit, and firm stock across different sections, with the manufacturing sector serving as the baseline group.

The sectoral heterogeneity analysis reveals three distinct patterns. The sectoral heterogeneity analysis reveals three distinct patterns. First, manufacturing and other traditional industries display predominantly negative effects. Broadband access leads to a 12.4 percent reduction in firm entry, a 7.8 percent increase in firm exit, and a 9.3 percent decline in the stock of firms in manufacturing. This indicates that the manufacturing sector is the main driver of the aggregate pattern of declining entry and rising exit.

Second, the finance, public administration, and real estate sectors exhibit clear expansionary effects. In finance, broadband leads to a 52.2 percent increase in the stock of firms, while entry and exit remain unaffected, indicating growth through the expansion of incumbents rather than the arrival of new entrants. In public administration, broadband leads to a 39.9 percent increase in firm entry and a 24.9 percent increase in firm stock, suggesting that barriers in administrative and quasi-public services were reduced. In real estate, broadband results in a 44.1 percent increase in entry, a 58.0 percent increase in exit, and a 47.0 percent increase in firm stock, implying higher market turnover alongside overall expansion.

Table 4.4.10. The effect of broadband on firm entry, exit and stock number, by sectors.

	(1)	(2)	(3)
	Log of Entry	**Log of Exit**	**Log of Stock**
Broadband Access Index	-0.124***	0.0780**	-0.0930***
	(0.0380)	(0.0374)	(0.0297)
ConstructionXBroadband	0.00711	-0.274***	-0.211***
	(0.0597)	(0.0524)	(0.0520)
EducationXBroadband	0.0265	-0.469***	0.00774
	(0.0514)	(0.0544)	(0.0454)
FinanceXBroadband	0.0355	-0.139	0.522***
	(0.0838)	(0.0865)	(0.0827)
HotelsXBroadband	0.0831*	-0.265***	-0.0756*
	(0.0441)	(0.0478)	(0.0424)
PublicAdminXBroadband	0.399***	0.0220	0.249***
	(0.0594)	(0.0548)	(0.0579)
RealEstateXBroadband	0.441***	0.580***	0.470***
	(0.0526)	(0.0501)	(0.0532)
TransportXBroadband	0.133***	-0.0717	-0.0451
	(0.0472)	(0.0472)	(0.0402)
WholesaleXBroadband	0.0821**	-0.163***	-0.0116
	(0.0405)	(0.0363)	(0.0288)
Constant	3.184***	3.240***	5.393***
	(0.0866)	(0.114)	(0.0359)
Observations	13,968	13,417	15,131
R-squared	0.884	0.870	0.937
Control	YES	YES	YES
DistrictFE	YES	YES	YES
YearFE	YES	YES	YES
SectorFE	YES	YES	YES
District number	337	337	337
R2_within	0.0204	0.0541	0.0506

Notes: Estimates are based on sample period from 1997 to 2002. District fixed effects and sector effects and year fixed effects are controlled. Standard errors are in parentheses and clustered at the district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent. Base group is manufacturing sector.

Other sectors display more mixed responses. In construction, broadband leads to a 21.1 percent reduction in the stock of firms, consistent with competitive pressures and market consolidation, while exits decrease by 27.4 percent. In hotels, broadband results in an 8.3

percent increase in firm entry and a 26.5 percent reduction in exits, yet firm stock still declines slightly by 7.6 percent with weak significance. In wholesale, broadband leads to an 8.2 percent increase in entry and a 16.3 percent reduction in exits. In transport, broadband causes a 13.3 percent increase in firm entry. By contrast, in education, broadband leads to a sharp 46.9 percent reduction in exits. These patterns underscore the sector-specific nature of broadband's effects and the complexity of jointly interpreting entry, exit, and firm stock.

The sectoral evidence further shows that the relationship between entry, exit, and overall firm stock is not straightforward. This complexity suggests that broadband's effects on firm dynamics cannot be attributed to a single mechanism. We therefore remain cautious in drawing causal inferences and emphasize the need for a nuanced interpretation that considers entry, exit, and stock together.

4.5 Discussion

In this chapter, we examine the impacts of broadband infrastructure on business entry and exit. At the district level, the broadband rollout is associated with a short-term increase in firm exits, while its effect on firm entry is negative and significant. One interpretation is that broadband rollout temporarily raises entry barriers, thereby discouraging new firms from entering. At the same time, lower information and transaction costs intensify competition, which contributes to higher exit rates among incumbent firms.

Our sectoral heterogeneity analysis shows that the impact of broadband is highly uneven across industries. Traditional sectors such as manufacturing and construction are the main drivers of the aggregate decline in entry and rise in exit, reflecting contractionary effects and heightened competitive pressures. By contrast, finance, public administration, and real estate exhibit expansionary dynamics, with real estate in particular showing strong gains across entry, exit, and stock, consistent with greater market dynamism. Other service-oriented sectors, including wholesale, transport, and education, display more mixed responses, combining higher entry, lower exits, or selective increases in firm stock. Overall, these findings indicate that broadband reshaped market structures asymmetrically: eroding the position of traditional industries while facilitating expansion and reallocation in service-based sectors.

In summary, the estimates of firm entry and exit indicate that broadband had asymmetric effects, with the overall pattern driven mainly by higher firm exits. This suggests that traditional firms relying on local market power were unable to withstand the intensified competition brought by broadband and were forced out of the market. Although broadband access enabled local firms to reach wider customer bases, it simultaneously exposed them to increased competition from remote firms entering local markets through online channels. Overall, the results show that broadband had a stronger and more significant positive effect on firm exits, while its negative effect on firm entry was smaller and less robust.

From a policy perspective, policymakers therefore need to complement broadband rollout with targeted measures that strengthen the resilience and competitiveness of traditional industries, for instance by supporting digital skills development, organisational upgrading, and access to complementary technologies. At the same time, the expansionary effects observed in services point to the importance of fostering innovation and entrepreneurship in sectors that are better positioned to leverage digital connectivity. Such differentiated policy support could help ensure that broadband contributes not only to market reallocation, but also to more inclusive and sustainable local economic growth.

Building on this chapter's findings on firm entry and exit, the next chapter further explores the underlying mechanisms by examining how broadband access affects firm performance, providing deeper insights into why the observed patterns of contraction and expansion emerge across sectors.

Chapter Five Broadband infrastructure and firm performance

5.1 Introduction

The purpose of this chapter is to assess the impact of broadband infrastructure on firm revenue and productivity. First of all, we use continuous broadband index as our base baseline specification; then we employ a staggered difference-in-differences model and an event study approach as our robustness check to estimate the causal effect on firm performance and productivity following broadband access. Additionally, the chapter examines whether the impact of broadband deployment varies based on factors such as firm size, industry type, and urban-rural location. Finally, the chapter explores the effects of variations in broadband intensity resulting from the physical characteristics of ADSL broadband technology.

Over the past two decades, the global economy has been characterized by rapid advancements in information technology. It is widely acknowledged that information infrastructure falls under the definition of a general-purpose technology (Bresnahan and Trajtenberg, 1995). The exchange of information has led to a significant reduction in social costs for firms and has been broadly applied across industrial sectors, thereby stimulating overall innovation and productivity. As a result, countries have heavily invested in broadband infrastructure, with Internet technologies evolving from broadband to 4G and fibre optics. Digital infrastructure has been continuously upgraded and replaced since 2000. This has not only led to substantial capital investment in information infrastructure by countries but also significant capital investment in ICT (Information and Communication Technology) products by firms. However, not all companies have benefited from these investments. Some evidence suggests that Internet investments have led to the decline of traditional businesses, as increased online activities have intensified competition and reduced offline profits (Brynjolfsson et al., 2009). Additionally, some firms that invested in ICT have not achieved the expected returns, resulting in bankruptcies (Lemos, 2000). These challenges related to information technology have been a subject of debate since the Solow Paradox (Acemoglu et al., 2014).

Moreover, numerous theories have sought to explain whether and how information and network technologies have transformed economic activities. Goldfarb and Tucker (2019) summarize several key theories that explain how broadband reduces firm costs. The first is the reduction in search costs; low-cost communication enhances research collaboration within organizations, leading to improved organizational efficiency (Garicano, 2000; Bloom et al., 2014). The Internet also enables firms to quickly serve a large number of customers, thereby improving transaction efficiency (Hagiu, 2012). Third, broadband accelerates market matching, whether in labour markets (Autor, 2001) or retail markets (Borenstein and Saloner, 2001; Bakos, 2001). However, some literature suggests that while digital technology adoption improves efficiency, the impact on firm organization in equilibrium depends on the nature of the technology and how its specific characteristics influence the trade-off between competitive pressures at the firm's boundaries (Forman and McElheran, 2013). The second point is the low replication costs and low transportation costs. Information technology has led to the digitization of services and products, where the replication cost of digital goods is nearly zero. The convenience of online transactions makes consumers more inclined to shop online to avoid the transportation costs associated with carrying items from stores (Pozzi, 2013; Loginova, 2009). It has even made the negative impact of distance in cross-border sales less significant (Lendle et al., 2016).

Empirical research also shows that broadband development benefits various economic and social outcomes. These factors include national-level GDP growth (Czernich et al., 2011), the promotion of international trade (Freund and Weinhold, 2004; Malgouyres et al., 2021), increased wages and employment growth among highly skilled workers (Forman et al., 2012; Akerman et al., 2015), and varying degrees of housing price increases due to broadband intensity (Ahlfeldt et al., 2017). Additionally, some studies have found that broadband Internet impact income inequality between urban and rural areas (Fan et al., 2018) and have a negative effect on social and political participation (Geraci et al., 2022).

However, empirical research at the firm level remains limited. The primary reason is the issue of endogeneity in information technology, as firms actively invest in broadband to gain returns. For example, many studies use variables such as the number of Internet-related employees, computer users, and corporate email accounts, but these factors cannot entirely eliminate the endogeneity problems. In contrast, we exploit the nature of broadband rollout as infrastructure. Once a region establishes a broadband network, communication and information acquisition costs are reduced for the entire area, allowing all firms to benefit from this infrastructure regardless of whether they individually adopt the new broadband technology (Gaspar and Glaeser, 1998).

Even though several firm-level empirical studies have emerged recently, their results remain controversial. The study most closely related to ours utilizes firms' ICT capital, but the findings still does not provide clear evidence of a positive effect on firm productivity. (DeStefano et al., 2018). Moreover, substantial cross-country differences in broadband deployment suggest that, while broadband is widely regarded as infrastructure, its impact may vary considerably depending on national industrial structures. For example, results from

Europe are not significant (DeStefano et al., 2023; Canzian et al., 2019), whereas findings from the United States are significant (Grimes et al., 2012; Kim and Orazem, 2017;). Our objective is to assess how broadband connectivity affects firm performance and productivity. Ultimately, we aim to understand how broadband technology has reshaped the industrial structure of developed countries in the digital age.

The main research questions of this chapter are:

1. Does the expansion of local Internet access improve firm performance and productivity?
2. How does broadband's impact on performance and productivity change over time, and are there any anticipated or enhanced effects?
3. To what extent do pre-existing characteristics such as industry structure, firm size, and location influence the effect of broadband on firms?

We also leverage the context of the UK broadband rollout from 1998 to 2002 as a quasi-natural experiment. The background and data are drawn from the early phased rollout of broadband in the UK during the period from 1999 to 2002. This rollout was driven by internal decisions made by BT, with early goals focused on widespread coverage, providing an exogenous basis for our study. Again, we use the continuous broadband index as our baseline model, then we applied a Difference-in-Differences (DID) approach along with the corresponding event study method to explore the impact of broadband on firm performance as robustness check. We evaluate several firm performance indicators, including turnover, employment, and gross value added (GVA). To measure productivity, we employ labour productivity, defined as turnover per employee and GVA per employee, to capture potential differences in impact.

Our contribution to this field lies in assessing whether broadband adoption enhances firm performance and productivity, while also examining the heterogeneous effects of broadband infrastructure across industries and firm sizes.

First, we do not find significant effects of broadband access on overall firm performance, even after conducting difference-in-differences robustness checks. However, our event study analysis reveals a positive and significant impact of broadband on firm size, measured by employment. This finding complements DeStefano et al. (2023), who also report that broadband fosters firm size expansion. Importantly, we find that this effect becomes significant two years after broadband rollout, with employment increasing by 5%, suggesting a time-lagged effect. Moreover, we find that this positive effects strengthen over time, providing supplementary evidence to DeStefano et al. (2018).

Second, our heterogeneity analysis sheds light on why firm-level studies often yield insignificant average results: broadband exerts opposite and significant effects across firms of different sizes and industries. From the perspective of firm size, we find that while both small and large firms benefit from broadband in terms of turnover, their responses in employment and productivity diverge. Large firms tend to reduce employment while improving labour productivity, whereas small firms expand employment but experience a decline in labour productivity. This partially supports Ackermann et al. (2015), who show that broadband increases output and wages among high-skilled workers while reducing them for low-skilled workers. We interpret these findings cautiously: broadband creates opportunities for market entry and business expansion, prompting small firms to increase headcount, but their limited managerial capacity, skills, and capital lead to efficiency losses. By contrast, large firms leverage broadband to optimize operations and substitute labour with technology, achieving productivity-driven growth. In terms of industry-level heterogeneity. The labour-intensive industries such as catering and retail, broadband primarily drives workforce expansion, accompanied by declining productivity. By contrast, in sectors such as motor trade, the gains are realized through efficiency improvements, with both GVA and labour productivity increasing. These results also help explain the findings reported in Chapter 4. In addition, we find that firms in rural areas receive positive effects in both turnover and labour productivity with weak significance. This provides new evidence on the role of broadband in supporting firms in rural areas, complementing the literature on regional digital divides.

Overall, our findings provide novel evidence that broadband, as a form of digital infrastructure, has heterogeneous rather than uniform effects. Its impact varies systematically with firm size, industry characteristics, and urban context, which helps explain why the effect of broadband on firm performance is often insignificant in firm-level studies.

The chapter is organized as follows. Section 5.1: Introduction. Section 5.2: Data section. This section covers the definition of firm performance, data collection, and a descriptive summary. The primary data source is the Annual Respondents Database (ARD), and our regression sample spans from 1997 to 2002.Section 5.3: Methodology. We discuss our methodology and datasets we used. Section 5.4: Empirical Results. This section presents our baseline findings, our robustness checks and our heterogeneity analysis. Section 5.5: Conclusion. We conclude with a summary of our results and their implications.

5.2 Data

In this section, in order to explore the causal effect of broadband access on firm performance and test our four hypotheses. We combine three main sources of information: a unique district-level broadband Internet availability, firm-level information Dataset-Annual Respondents Database (ARDx), and district-level economic information. We provide a description of our data in the following subsections.

Dependent Variable-Annual Respondents Database

We use several dependent variables derived from the Annual Respondents Database (ARD), which provides firm-level performance data from 1998 to 2008. The ARD contains our main outcome variables as well as firm-level control variables. The firm performance indicators include turnover, employment, gross value added (GVA), and two measures of labour productivity: GVA per employee and turnover per employee. The employment is based on the Inter-Departmental Business Register (IDBR) employment. It includes both full-time and part-time employees

To assess the impact of broadband access on firm productivity, we rely on two widely used proxy measures at the firm level: GVA per employee and turnover per employee. GVA per worker captures the economic value generated per unit of labour input, serving as a fundamental measure of productivity. Turnover per worker reflects revenue generated relative to the workforce and is often used where value-added data are noisy or prices are not well measured. These measures are widely adopted in firm-level studies because they are straightforward to calculate from available data.

While labour productivity measures (GVA per employee and turnover per employee) are widely used and relatively easy to calculate, they also have important limitations compared with Total Factor Productivity (TFP). First, labour productivity does not account for the contribution of capital and intermediate inputs, and thus may overstate or understate efficiency gains when broadband affects labour–capital substitution or changes production structures. Second, turnover-based productivity is sensitive to price variation and firm-level mark-ups, which may bias cross-firm or cross-industry comparisons. By contrast, TFP provides a more comprehensive measure of productivity, but its estimation requires detailed data on capital stock and intermediate inputs that are difficult to obtain, especially for service firms. For this reason, we adopt labour productivity measures as a more feasible approach. Comparisons with TFP-based studies (Cardona et al., 2013; DeStefano et al., 2023) further suggest that ICT tends to have a stronger impact on labour productivity than on TFP, which reinforces the validity of our choice.

In addition, we rely on the ARD to obtain further firm-level covariates, including sector classification, foreign ownership status (whether belongs to UK), multi-plant structure (whether reports multiple plants), and telecommunications costs.

The ARD also provides information on firm location. We rely on the data at the local unit level (ARDLU) to obtain firm location covariates such as postcode and their local authority location (postcode-district -region), and we also collect its Lower Super output area(LSOA) level urban/rural classification.

There are approximately 50,000 firms surveyed each year from 1998 to 2008.And our sample period was only limited from 1998 to 2002.

Independent variable-ADSL Broadband Dataset

The data we used is the same as in Chapter Four which built in chapter 2. We use broadband access index Z_{jt} as our independent variable. The broadband access index Z_{jt} for each Local Authority/district j is the continuous index of each broadband access in the local authority/district. The index is based on serveral dataset. First, the local exchange dataset, it is managed by Ofcom, the regulatory authority for the UK's telecommunications industry. This data is publicly available. We obtained the data from the website -- SamKnows.com. Simultaneously, to acquire the geographical coverage of each LE, we accessed data from the commercial data website PointTopic.com. This data records the area's postcodes and scope covered by a given LE. In the end, we can match nearly 95% of postcode locations. However, it's important to note that the Ofcom data does not cover the Hull area.

Control Variables-Socioeconomic Data

Considering the rollout of broadband was concentrated within urban areas, we control for district-level covariates. We collect district-level GDP and population from the ONS; these are open public data available from Nomis.com. Again, we use initial GDP per capita as our main district-level control variable in this chapter.

Sample selection

We merge our ARDx, SamKnows and Point Topic datasets through firm location (postcode–district–region), which allows us to assign each firm to a district. First, we drop the Hull districts and Northern Ireland, which have limited broadband information. Additionally, since firms may change their locations during the sample period, we exclude firms that change location and firms that enter the survey after treatment begins.

Table 5.2.1 shows the summary statistics for the sample from 1998 to 2002. The main output variables are employment, turnover and gross value-added. The firm gross value added(GVA) is calculated from turnover minus the total purchases. Some firms have no information about GVA, and we lost some observations when we used GVA. The mean value of turnover is 16208 thousand pounds. The standard deviation is 157566, indicating that the revenues of sample firms take a broad range of values. On average, firms hire 136 employees, indicating that the sample firm size is at medium level. The firm gross value added is 5584 on average, and the standard deviation is 49855, which also reflects a wide range of values for the firm output. The firm age is 14 on average, indicating that the firm in the sample has a long operating term. Only 14% of firms belong to foreign countries, indicating our sample mainly focuses on domestic firms. And 73% of firms are located in urban areas, which shows our research mainly considers urban firms. The average No.of local units is 3, but the median No.of Local units is 1, which indicates that the firms tend to have only one business establishment. The average linear distance from the Postcode to LE is 1.27km and the average copper length is 3.07km.

Table.5.2.1 Summary statistics for sample period 1998 to 2002.

	Mean	**SD**	**Median**	**N**
Employment	136.58	868.69	18	212813
Turnover(thousand)	16208.83	157566.48	890	212813
Gross Value Added(thousand)	5584.55	49855.38	442	175287
Foreign ownership	0.15	0.36	0	212813
Age	13.96	8.99	12	206206
Urban area	0.73	0.44	1	212813
No. of Local Units	3.13	24.85	1	212813
Linear distance from the Postcode to LE(m)	1277.33	957	1061.82	187467
The length of the copper line (km)	3.07	1.5	2.82	187467
Purchases of telecommunication	85	2496.61	3.74	212813
Purchases of computers and related services	117.75	2454.49	1	212813
Firm number in one local authority(district)	193.72	176	138	212813
GDP(million)	4287.39	4553.42	2816	212813
Population	217449.25	158899.22	159401	212813
Zjt(Broadband access index)	0.1	0.21	0	212813

Note： Outcome variables and firm inputs

We also look at the sector-level statistics. Table 5.2.2 shows the distribution of sector counts by years. [7] Table shows that the PD sector account for the 25% in our regression sample.

[7] Following the definition of the ARD survey, we use the sector definition based on sic-03 two digital codes. The Catering

And services sector like Retail, wholesale and other business cover 50 %. This indicates that our sample is largely composed of service industry activities. According to the ARD dataset definition, it is representative of the UK economic structure.

Table 5.2.2 Tabulation of sector year

Sector, defined by SIC03	Year					
	1998	1999	2000	2001	2002	Total
Catering (CA)	2550	2606	2239	2091	1979	11465
Construction (CN)	3552	4052	3595	3309	3131	17639
Motor trade (MT)	2305	2413	2035	1840	1671	10264
Production (PD)	11705	11569	10230	9597	8499	51600
Property(PR)	1338	1540	1069	928	894	5769
Retail (RE)	6143	5844	4667	4129	3785	24568
Other service (ST)	16090	16959	12727	12108	11009	68893
Wholesale (WH)	5571	5466	4248	3780	3550	22615
Total	49254	50449	40810	37782	34518	212813

Table.5.2.3 The number of occurrences of the firm during the sample period

The number of occurrences of the firm	Freq.	Percent	Cum.
1	112291	74.90	74.90
2	23503	15.68	90.58
3	6813	4.54	95.12
4	3508	2.34	97.46
5	3809	2.54	100.00
Total	149924	100.00	

The sample consists of approximately 212,813 firm–year observations covering 149,924 firms. The dataset is unbalanced, with many firms appearing in the ARD survey for only a single year. As shown in Table 5.2.3, more than 100,000 firms are observed in just one period, while only 3,809 firms appear in at least five periods. In our baseline regressions with firm fixed effects, single-year observations are excluded.

(CA) sector cover sic55, Construction (CN) cover sic45.Motor trade (MT) cover sice50. Production (PD) sector cover sic1/2/10-41. The production sector includes agriculture, mining and manufacturing. Property (PR) cover sic70. Retail (RE) cover sic52. Other service (ST) cover 60-93, which cover business services and telecom and communication services. Wholesale(WH) cover sic51.

5.3 Research Design

The rapid expansion of broadband Internet access has significantly influenced businesses. However, since broadband connections can, in principle, affect firms across many dimensions, the underlying mechanism remains unclear. In this section, first, we present a simple theoretical model (Hjort and Tian, 2023) that helps us fill this gap. Then, using TWFE method and staggered difference-in-differences approach, we seek to provide robust evidence on the causal relationship between broadband access and enhanced firm performance.

A simple model

The model we follow from (Hjort and Tian, 2023) highlights production channels through which the technological shock induced by broadband Internet roll-out can impact firm output and productivity. Consider an economy that consists of many firms, indexed by j. Each firm produces with the following production function:

$$Y_i = F(L_i, K_i; \theta) \equiv A_i(\theta)[A_i^L(\theta)L_i(\theta)][A_i^K(\theta)\ K_i(\theta)] \quad (5.0)$$

In the production function, Y_i represents the output, $L_i(\theta)$ denotes the aggregate labour inputs, and $K_i(\theta)$ is a composite of all other production inputs, including capital. Note that $L_i(\theta)$ and $K_i(\theta)$ represent quality adjusted quantity of production inputs: $L_i(\theta)$ for example, can be interpreted as efficiency units of workers that firm i hires. A_i^L A_i^K are technological parameters. θ represents the level Internet connectivity in the economy, which is assumed to be exogenously given—i.e., conditioning on Internet being available in the country, firms take Internet technology as given and do not selectively adopt the technology in their production. Given the specification in (5.0), Internet connectivity, can potentially affect firm's total factor productivity and factor-specific productivity.

In the setup from (Hjort and Tian, 2023), which allows Internet connectivity to affect economic outcomes through multiple channels, we focus on the production function channel, or supply-side channel, emphasising the Internet's impact on firm or labour productivity.

The supply-side effect of Internet connectivity can be summarized as the better Internet connectivity improves firm productivity, $\frac{dY_i}{d\theta} > 0$. And this total effect of Internet on firm productivity can be realized through several channels.

Firstly, Internet connectivity can enhance worker efficiency, functioning either as a labour-enhancing or labour-saving technological change. By defining labour productivity as $\frac{dY_i}{dL_i}$ we can summarize the labour productivity enhancing effect of Internet as a second-order effect on output through labour productivity, i.e. $\frac{d}{d\theta}(\frac{dY_i}{dL_i}) > 0$. Internet access can enhance labour productivity directly, making Internet adoption a labour-biased technical change. This can be achieved, for example, through an increase in $\frac{dA_i^L(\theta)}{d\theta} > 0$.

Furthermore, Internet access can promote human capital development by providing opportunities for on-the-job training and other training programs outside the workplace. This can also increase workers' productivity, i.e., $\frac{dL_i}{d\theta} > 0$

In addition, Internet connectivity can also affect the firm's total factor productivity (TFP). The model represents this as a direct impact of the Internet on firm productivity, i.e., $\frac{dA_i}{d\theta} > 0$.

Identification Strategy

We employ a Two-way fixed effect model (TWFE) approach to design model specifications to examine the relationship between firm performance and broadband access index. The model specifications are as follows:

$$Y_{ijt} = a + \beta Z_{jt} + \delta X_{it} + \sigma \mathrm{X}_{\mathrm{jt}} + \alpha_i + LA_j + Sector_\rho + Year_t + \epsilon_{ijt} (5.1)$$

where Z_{jt} refers to the continuous index form of broadband access at local authority/district j at time t from equation (2.1) which we built at section 2.3. Y_{ijt}represents an outcome variables,such as firm revenue,firm employment and firm productivity for firm i which participated in survey in year t in Local AuthorityLA_j. X_{it} *and* X_{jt} are vector for firm-level and District(LA) level controls, respectively. We estimate equation (5.1) to control the different fixed effects, firm fixed effect$-$ α_i, Local authority(district) fixed effect -, LA (district) fixed effect LA_j and sector fixed effect (based at SIC03 level) - $Sector_\rho$ and year fixed effect- $Year_t$ and we also use interactions of sector-year fixed effects. Our standard error ϵ_{ijt} cluster at the district level.

5.4 Empirical Results

5.4.1. Baseline Regression results

Table 5.4.1.A to Table 5.4.1.E present the estimated average effects of broadband availability index on firm performance outcomes including turnover, employment, and labour productivity. The results suggest that the introduction of ADSL broadband in a district has no significant effect on firm performance.

In each panel, the first column reports estimate from a basic specification that includes firm fixed effects, district fixed effects, year fixed effects, and Broadband Access Index. The second column adds firm-level and district-level control variables. Firm-level controls include a multi-plant indicator(Multi-plant), foreign ownership status(Foreign), firm age(Age), and the log of telecommunication costs (Lntele). The district-level control is the log form of initial district level GDP per capita interact with year (GDP Control). In the third column, we

Table 5.4.1. Baseline results on firm performance

Panel A	(1)	(2)	(3)	(4)
	Log of Firm Turnover			
Broadband Access Index	0.0500**	0.00155	0.00168	-0.00233
	(0.0226)	(0.0177)	(0.0176)	(0.0175)
Foreign		0.0308***	0.0310***	0.0304***
		(0.00932)	(0.00931)	(0.00916)
Age		0.0205***	0.0204***	0.0201***
		(0.00396)	(0.00396)	(0.00398)
Multi-plant		0.132***	0.131***	0.128***
		(0.0160)	(0.0160)	(0.0158)
Lntele		0.0375***	0.0379***	0.0374***
		(0.00579)	(0.00581)	(0.00577)
Constant	8.461***	7.356***	7.358***	7.437***
	(0.00341)	(0.195)	(0.195)	(0.183)
Observations	99,177	93,779	93,779	93,779
R-squared	0.940	0.945	0.945	0.946
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
Cluster	District	District	District1	District
R2_within	0.000241	0.00774	0.00774	0.00705
District_number	377	377	377	377
GDPControl		YES	YES	YES
YearFEXSectorFE				YES
SectorFE			YES	

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

additionally, include sector fixed effect and year fixed effects separately. In the fourth column, we use the sector fixed effect interact with year fixed effect to account for time-varying sector-specific shocks that might affect firm outcomes.

Across specifications, the estimated effects remain relatively stable. We focus on Column (4), as it controls for the most comprehensive set of fixed effects.

Table 5.4.1, Panel A presents the estimated effects of broadband availability on firm turnover, based on equation (5.1). Across four specifications, the dependent variable is the log of firm turnover. Column (1), our baseline specification, controls for firm, district, and year fixed effects, and clusters standard errors at the district level. The result shows a significant and positive effect, suggesting that broadband index is positively associated with firm turnover in a simple fixed-effect model. Broadband access index increase 5% firm turnover. In Column (2), we incorporate a set of firm-level and district-level controls. Once these controls are added, the coefficient on the Broadband Access Index becomes small and insignificant, indicating that the initial association may be driven by observable characteristics.

Column (3) adds sector fixed effects, while Column (4) further introduces sector-by-year fixed effects to control for unobserved shocks that affect industries differently over time. In this specification, which serves as our preferred baseline model, the coefficient on broadband remains insignificant and close to zero. This suggests that broadband access does not lead to a significant average increase in firm turnover.

Table 5.4.1.B presents the estimated effects of broadband access on firm-level employment. Across all four specifications, the dependent variable is the log of employment, measured using data from the Inter-Departmental Business Register (IDBR). The IDBR employment variable captures both full-time and part-time employees, thereby providing a more consistent and comprehensive measure of firms' actual labour input.

Column (1) shows a significant positive association between broadband access and employment using a basic fixed-effects model. It implicates broadband access index increase 4.2% firm employments. This relationship remains significant, though weaker, in Columns (2) and (3), which include firm- and district-level controls and sector fixed effects. However, once sector-by-year fixed effects are added in Column (4), the coefficient on broadband becomes insignificant. The positive effect of broadband on employment does not persist once sector-specific time trends are controlled for. Consequently, identification relies only on within-industry, cross-district variation in broadband access, where the effects are weaker and more heterogeneous.

Panel B	(1)	(2)	(3)	(4)
	Log of Firm Employment			
Broadband Access Index	0.0419***	0.0182*	0.0179*	0.00727
	(0.00997)	(0.00992)	(0.00995)	(0.00910)
Foreign		0.00248	0.00275	0.00861**
		(0.00396)	(0.00394)	(0.00409)
Age		0.00749***	0.00742***	0.00740***
		(0.00163)	(0.00164)	(0.00163)
Mutli-plant		0.283***	0.282***	0.276***
		(0.0108)	(0.0107)	(0.0106)
Lntele		0.0490***	0.0496***	0.0474***
		(0.00378)	(0.00377)	(0.00378)
Constant	4.373***	3.789***	3.789***	3.870***
	(0.00151)	(0.0636)	(0.0639)	(0.0517)
Observations	99,970	94,378	94,378	94,378
R-squared	0.976	0.979	0.979	0.979
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
Cluster	District	District	District1	District
R2_within	0.000700	0.0494	0.0494	0.0464
District_number	377	377	377	377
GDPControl		YES	YES	YES
YearFEXSectorFE				YES
SectorFE			YES	

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5.4.1.C examines the effect of broadband access on firm-level gross value-added, measured as the log of gross value added(GVA). Column (1), which includes only firm, district, and year fixed effects, shows a positive and significant coefficient on the Broadband Access Index. It shows broadband access index increase 4.2% GVA. However, the magnitude of this effect declines and becomes insignificant in Columns (2) to (4), once firm-level and district-level controls, sector fixed effects, and sector-by-year fixed effects are sequentially included. The results suggest that the initial positive association between broadband access and gross value added(GVA) is driven by observable firm and sector characteristics, rather than a robust causal relationship. In the fully controlled specification (4), broadband availability even shows a negative but insignificant effect on firm GVA. When we turn to firm-level labour productivity, Table 5.4.1, Panels D and E show no significant effect of broadband access on either GVA-based or turnover-based measures across specifications. This supports the view that broadband infrastructure alone is not sufficient to enhance firm productivity without complementary organisational or technological investment (Brynjolfsson & Hitt (2000)).

Panel C	(1)	(2)	(3)	(4)
	Log of Firm Gross Value Add(GVA)			
Broadband Access Index	0.0424**	0.00980	0.00955	-0.00437
	(0.0173)	(0.0163)	(0.0163)	(0.0154)
Foreign		-0.0105	-0.0103	7.25e-05
		(0.00804)	(0.00805)	(0.00805)
Age		0.00128	0.00126	0.00101
		(0.00244)	(0.00244)	(0.00244)
Mutli-plant		0.105***	0.104***	0.0961***
		(0.0139)	(0.0140)	(0.0140)
Lntele		0.0534***	0.0538***	0.0504***
		(0.00741)	(0.00738)	(0.00751)
Constant	7.654***	7.176***	7.176***	7.325***
	(0.00263)	(0.104)	(0.104)	(0.0856)
Observations	81,835	79,436	79,436	79,436
R-squared	0.952	0.956	0.956	0.956
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
Cluster	District	District	District1	District
R2_within	0.000260	0.00738	0.00740	0.00592
District_number	377	377	377	377
GDPControl		YES	YES	YES
YearFEXSectorFE				YES
SectorFE			YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Our finding that broadband access does not significantly increase firm performance diverges from several recent studies in the UK and Europe. For example, Canzian et al. (2023) document significant increases in firm turnover following broadband rollout in rural areas. Similarly, De Stefano et al. (2023), using a fuzzy regression discontinuity design based on ADSL infrastructure boundaries, report positive associations between broadband availability and turnover in their OLS estimates. These studies support the conventional view that broadband access expands market opportunities and customer reach.

However, our results provide only limited support for this narrative. Once sector-by-year fixed effects and firm and district controls are included, the average effect on turnover becomes insignificant. This suggests that broadband does not generate uniform performance gains but may instead intensify competition and drive market reallocation, benefiting some firms while disadvantaging others. This interpretation is consistent with the firm entry and exit dynamics documented in Chapter 4.

At the same time, our employment results are in line with De Stefano et al. (2023), who also find that broadband access increases firm-level employment. Moreover, our finding of insignificant effects on labour productivity is consistent with De Stefano et al. (2023) and Bertschek et al. (2013), who similarly conclude that broadband adoption alone does not improve productivity.

These comparisons suggest that the benefits of broadband are unlikely to be evenly distributed across firms. We argue that, rather than generating uniform improvements, broadband may produce differentiated effects shaped by firm size, industry and regional context. To explore this possibility, Section 5.4.3 examines how broadband interacts with firm size, industry type, and urban location.

Panel D	**(1)**	**(2)**	**(3)**	**(4)**
	Firm Productivity(GVA)			
Broadband Access Index	0.00864	0.00222	0.00222	-0.000743
	(0.0154)	(0.0161)	(0.0161)	(0.0160)
Foreign		-0.0154*	-0.0154*	-0.00987
		(0.00848)	(0.00848)	(0.00854)
Age		-0.00540**	-0.00533**	-0.00543**
		(0.00247)	(0.00247)	(0.00248)
Mutli-plant		-0.171***	-0.171***	-0.174***
		(0.0171)	(0.0170)	(0.0171)
Lntele		0.00415	0.00392	0.00258
		(0.00705)	(0.00707)	(0.00715)
Constant	3.231***	3.428***	3.427***	3.475***
	(0.00233)	(0.0908)	(0.0914)	(0.0909)
Observations	81,823	79,431	79,431	79,431
R-squared	0.834	0.839	0.839	0.839
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
Cluster	District	District	District1	District
R2_within	9.26e-06	0.00439	0.00436	0.00446
District_number	377	377	377	377
GDPControl		YES	YES	YES
YearFEXSectorFE				YES
SectorFE			YES	

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Panel E	(1)	(2)	(3)	(4)
	Firm Productivity(Turnover)			
Broadband Access Index	0.0121	-0.0145	-0.0141	-0.00759
	(0.0197)	(0.0170)	(0.0170)	(0.0173)
Foreign		0.0281***	0.0281***	0.0215**
		(0.00925)	(0.00925)	(0.00915)
Age		0.0134***	0.0134***	0.0131***
		(0.00392)	(0.00392)	(0.00395)
Mutli-plant		-0.152***	-0.151***	-0.148***
		(0.0162)	(0.0162)	(0.0162)
Lntele		-0.0116*	-0.0119**	-0.0102*
		(0.00594)	(0.00594)	(0.00595)
Constant	4.082***	3.560***	3.561***	3.560***
	(0.00298)	(0.155)	(0.154)	(0.157)
Observations	99,150	93,773	93,773	93,773
R-squared	0.880	0.882	0.882	0.882
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
Cluster	District	District	District1	District
R2_within	1.32e-05	0.00382	0.00380	0.00383
District_number	377	377	377	377
GDPControl		YES	YES	YES
YearFEXSectorFE				YES
SectorFE			YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.4.2. Robustness Checks- Difference in Difference Framework

Our baseline results indicate that the Broadband Access Index has no significant effect on firm performance or productivity. To ensure robustness, and consistent with the approach adopted in Chapter 4, we employ difference-in-differences (DiD) and event study designs as our main robustness checks.

Difference in Difference Framework

To obtain estimates that can be more credibly interpreted as causal, we first utilize the Staggered Difference-in-Differences (DID) model assess the annual changes in firm performance among local authorities' level (Districts/LA) where ADSL has been activated versus those where it has yet to be activated. Since we have no information on broadband adoption by the firms in our sample, the estimated effects represent intention-to-treat effects.

The model specifications are as follows:

Traditional DiD Model:

$$Y_{ijt} = a + \beta Treated_{ijt} + \delta X_{it} + \sigma X_{jt} + \alpha_i + LA_j + Sector_p + Year_t + \epsilon_{ijt} (5.2)$$

Where Y_{ijt}represents an outcome variables,such as firm revenue,firm employment and firm productivity for firm i which participated in survey in year t in Local AuthorityLA_j. $Treated_{ijt}$ is an indicator for whether in year t, ADSL Broadband was activated at LA_j. X_{it} *and* X_{jt} are vector for firm-level and District(LA) level controls, respectively. We estimate equation (5.2) to control the different fixed effects, firm fixed effect$-$ α_i, Local authority(district) fixed effect -, LA (district) fixed effect LA_j and sector fixed effect (based at SIC03 level) - $Sector_p$ and year fixed effect- $Year_t$ and standard error ϵ_{ijt} cluster at the district level.

Event-study model

$$Y_{ijt} = \sum_{d=-3}^{d=-1} \beta_d \times 1(t = d + t_{j0}) + \sum_{d=0}^{d=2} \beta_d \times 1(t = d + t_{j0}) + \delta X_{it} + \sigma X_{jt} + \alpha_i + LA_j + Year_t + \epsilon_{ijt} \quad (5.3)$$

Where t_{j0} represent the year district experience ADSL treatment and term d represent the number of years away from ADSL broadband access treatment year.If d is negative, which means d years before the treatment year, if d is postive, it shows the d year after treatment year. We include a vector of 3 leads and 2 lags of broadband access which range from 3 periods before broadband access until 2 periods after broadband access. β_d represent the effect of broadband access/activation on firm performance, d years away from broadband access/activation and it is the main coefficient of our interest.

Difference in Difference Framework results

In this section, we present the Traditional DID estimates and event-study results on firm performance. Table 5.4.2 reports the DiD estimates with the full set of controls. Figures 5.4.1 to 5.4.5 display the event-study coefficient plots for different outcome variables, estimated using four approaches: BJ (Borusyak et al., 2021), DD (de Chaisemartin and D'Haultfœuille, 2020), CS (Callaway and Sant'Anna, 2021), and the conventional two-way fixed effects OLS. The Borusyak estimator includes only fixed effects, while the other three estimators additionally control for a full set of covariates, including firm characteristics, initial district GDP per capita, and fixed effects.

Table 5.4.2 Traditional DiD Model results

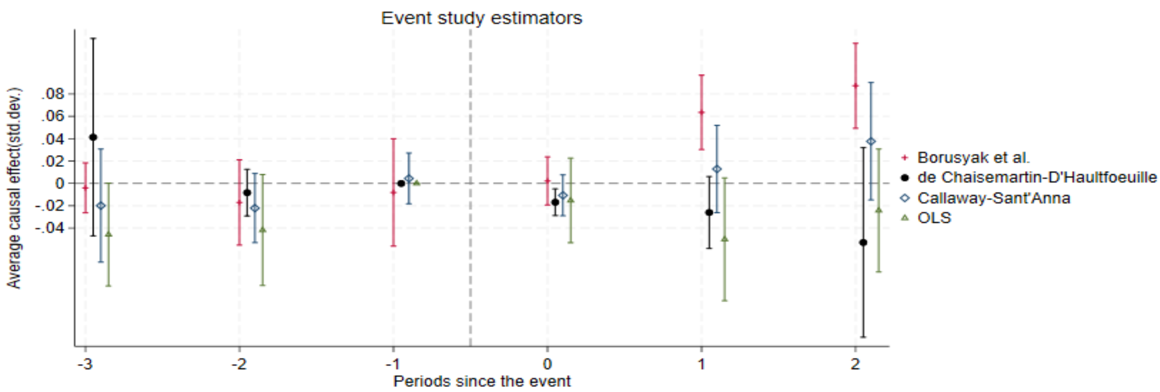
	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	Log of Firm Employment	Log of Firm GVA	Productivity (GVA)	Productivity (Turnover)
Treated	-0.000878	0.00191	0.00219	0.00337	-0.00203
	(0.00944)	(0.00481)	(0.00776)	(0.00849)	(0.00924)
Foreign	0.0304***	0.00867**	1.69e-05	-0.00990	0.0214**
	(0.00917)	(0.00409)	(0.00806)	(0.00854)	(0.00915)
Age	0.0201***	0.00740***	0.00101	-0.00543**	0.0131***
	(0.00398)	(0.00163)	(0.00244)	(0.00248)	(0.00395)
Multi-plant	0.128***	0.276***	0.0960***	-0.174***	-0.148***
	(0.0158)	(0.0106)	(0.0139)	(0.0171)	(0.0162)
Lntele	0.0374***	0.0474***	0.0504***	0.00259	-0.0102*
	(0.00577)	(0.00378)	(0.00751)	(0.00715)	(0.00594)
Constant	7.438***	3.865***	7.332***	3.481***	3.565***
	(0.180)	(0.0517)	(0.0838)	(0.0903)	(0.154)
Observations	93,779	94,378	79,436	79,431	93,773
R-squared	0.946	0.979	0.956	0.839	0.882
FirmFE	YES	YES	YES	YES	YES
YearFE					
DistrictFE	YES	YES	YES	YES	YES
Cluster	District	District	District	District	District
R2_within	0.00705	0.0464	0.00592	0.00447	0.00382
District_number	377	377	377	377	377
GDPControl	YES	YES	YES	YES	YES
YearFEXSectorFE	YES	YES	YES	YES	YES
SectorFE					

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.4.2. shows the coefficients of treatment are close to zero and insignificant in any specification. This simply means that firms in treated areas do not look different from firms in control areas. Since our setting involves a staggered adoption of broadband across districts, the traditional two-way fixed effects DiD estimates may not be fully appropriate. In staggered designs, treatment effect heterogeneity across cohorts and time can lead to biased estimates in conventional DiD models (Goodman Bacon, 2021). For this reason, we place greater emphasis on the event-study results, which allow us to trace the dynamic effects of broadband rollout more transparently and mitigate potential biases arising from staggered treatment timing.

Figure 5.4.1 presents the dynamic effects of broadband access on firm turnover using four event study estimators. Across all methods, Pre-treatment coefficients are close to zero and insignificant across all methods, supporting the parallel trends assumption and validating the common pre-trend requirement for causal interpretation. In the post-treatment period, estimates begin to diverge. BJ suggests a significant increase, while the other three estimators shows insignificant results at every post-event period. Overall, these findings indicate no robust evidence of significant average causal effects of broadband access on firm turnover in the two years following rollout, regardless of estimator choice.

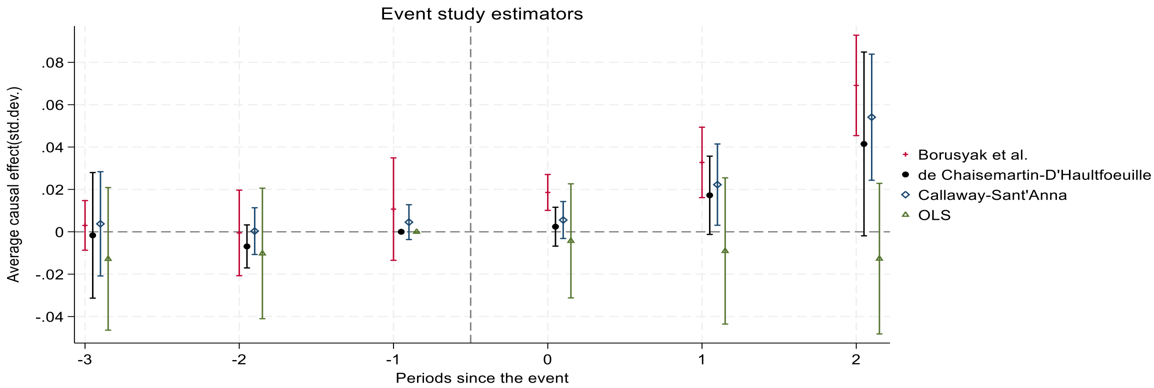
Figure 5.4.1 Event study effects of ADSL Broadband on firm turnover



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

Figure 5.4.2 plots the dynamic effects of broadband access on firm-level employment. All estimators show flat and insignificant pre-treatment trends, supporting the parallel trends assumption. In the post-treatment period, the estimated effects display modest increases across three robust estimators. Although most post-treatment coefficients are not statistically significant at the 5% level, they remain consistently positive in magnitude, particularly in year 2, where the estimates suggest a 5% increase in employment. This pattern indicates that the positive impact of broadband on employment materializes with a time lag, reflecting delayed adjustments in firms' hiring decisions. These findings are consistent with our baseline estimates in Table 5.4.1, Panel B, and with De Stefano et al. (2023), who argue that broadband may support firm size expansion.

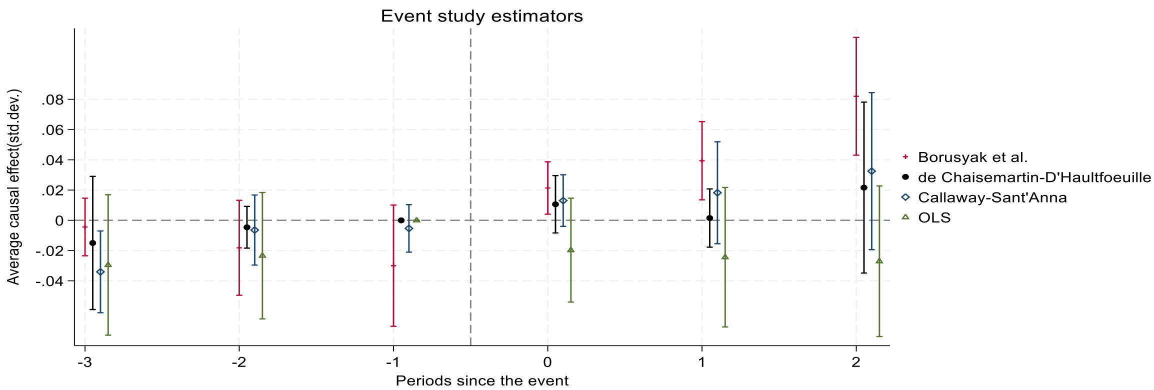
Figure 5.4.2 Event study effects of ADSL Broadband on firm employment



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

Figure 5.4.3 presents the event study estimates of broadband access on log of GVA. Across all estimators, pre-treatment coefficients are insignificant, supporting the parallel trends assumption. Post-treatment effects are uniformly positive but insignificant, suggesting that broadband access alone does not lead to immediate improvements in GVA.

Figure 5.4.3 Event study effects of ADSL Broadband on firm gross value added(GVA)

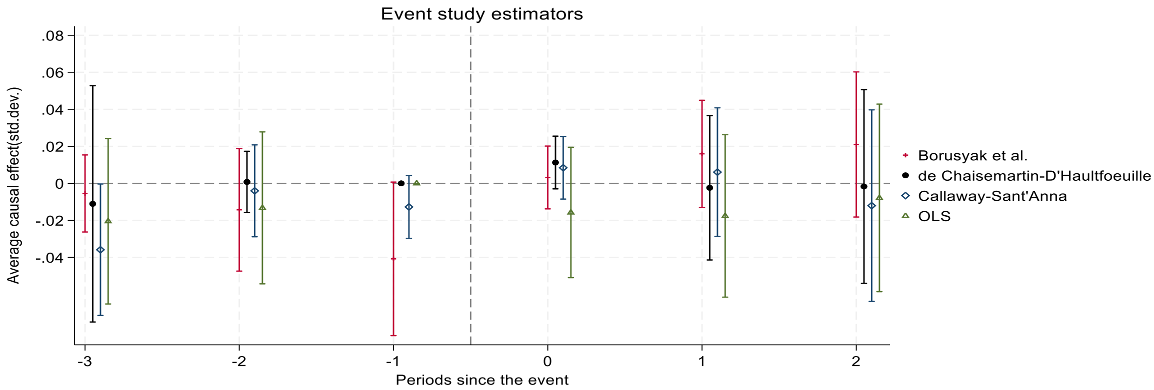


Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

Figures 5.4.4 and 5.4.5 present the dynamic effects of broadband access on labour productivity, measured respectively as GVA per employee and turnover per employee. In both cases, the pre-treatment estimates are small and insignificant, supporting the parallel trends assumption. In the post-treatment period, the results do not reveal robust productivity gains:

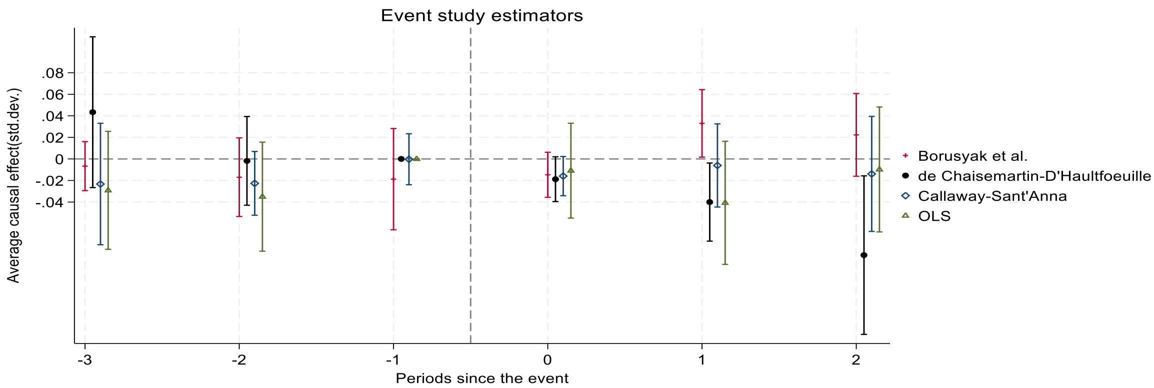
while the DD estimator shows a sharp negative effect for turnover-based productivity at t=2, this pattern is not replicated by the other estimators. Overall, the evidence indicates that broadband rollout does not generate significant short-run improvements in labour productivity, whether measured by GVA or turnover. These findings are consistent with De Stefano et al. (2023) and reinforce our interpretation that broadband access alone is insufficient to raise productivity without complementary organisational changes or technological investments.

Figure 5.4.4 Event study effects of ADSL Broadband on firm labour productivity (gross value added per worker)



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

Figure 5.4.5 Event study effects of ADSL Broadband on firm labour productivity(turnover per worker)



Note: This figure overlays the event-study plots constructed using four different estimators: a dynamic version of the TWFE model, equation (2), estimated using TWFE (in green with triangle markers); De Chaisemartin and d'Haultfoeuille (2020) (in black with circle markers); Callaway and Sant'Anna, (2021) (in blue with diamond markers) and Borusyak, Jaravel, and Spiess (2021) (in red with cross markers). The bars represent 95 per cent confidence intervals. Standard errors are clustered at the firm level.

Our event-study estimates suggest that local broadband infrastructure has a positive effect on firm performance, primarily through employment expansion. Firms in areas experiencing ADSL upgrades show higher employment, broadly consistent with De Stefano et al. (2018, 2023), although our results diverge from Canzian et al. (2019), who find turnover gains without employment growth, pointing to heterogeneous firm responses. Our event study further reveals a lagged employment effect, likely reflecting either delays between rollout and firm-level adoption or the gradual realization of organizational benefits. Importantly, employment effects follow a roughly linear upward trend over time, suggesting a persistent influence of broadband on firm growth and local labour markets. By contrast, we find no robust impact on gross value added or productivity measures, implying that in the early phase of digital infrastructure expansion, firms may scale up through hiring rather than immediate productivity improvements.

Given the relatively short time span covered by our dataset, it is not possible to assess whether the observed effects of broadband access on firm outcomes persist, intensify, or reverse over the longer term. This limitation highlights an important avenue for future research: studies drawing on extended panel data and detailed information on firm-level broadband adoption would be well placed to unpack the longer-run dynamics and mechanisms through which digital infrastructure shapes firm performance and productivity.

5.4.3. Heterogeneity analysis

Heterogeneity analysis

In this section, we examine whether factors such as industry sector, degree of urbanization, and firm size condition the extent to which firms benefit from broadband access. To do so, we incorporate initial factor condition level interact with the broadband access index in our heterogeneity analysis. We also examine the intensity of broadband effects on firm performance, with the results reported in the Appendix A.5.5.

Firm size

Previous literature provides mixed insights into the impact of Information and Communication Technology (ICT) on business revenues. DeStefano et al. (2018) found that ICT significantly boosts the revenue of both small and large enterprises, with a more pronounced effect on small businesses. In contrast, Haller and Siedschlag (2011) argue that larger firms are better positioned to leverage ICT for increased revenues, especially in online environments. Malgouyres et al. (2021) further emphasise that large enterprises rely less on regional information infrastructure for their ICT benefits, instead depending on their internally skilled ICT personnel and internal ICT investments. Small businesses, however, are more dependent on regional information infrastructure development.

Based on this, we hypothesize that large firms are less affected by broadband infrastructure. Our sample is categorized into small, medium, and large companies based on the number of employees in the first year of the sample. Companies with fewer than 50 employees are considered small businesses, those with 50 to 249 employees are categorized as medium-sized enterprises, and companies with more than 250 employees are classified as large enterprises. In our sample, small companies account for 30% of the total, medium-sized firms account for another 30%, and large companies make up 40%.

Specifically, we follow the method from Beck et al., (2010) estimate the following modification of equation (5.1):

$$Y_{ijt} = a + \beta_1 Z_{jt} + \beta_2 Z_{jt} * \text{Size} + \text{Size} + \delta X_{it} + \sigma \text{X}_{\text{jt}} + \alpha_i + LA_j + Sector_p + Year_t + \epsilon_{ijt} \quad (5.1.1)$$

Where Size represents the size group of the firm employment. The medium level firm is our base reference group. The rest of the variables are the same as our baseline regression model (5.1).

Firm Industry

Existing research suggests that information and communication technology (ICT) drives skill-biased technological change, prompting firms to adopt technologies that favor skilled labour and enhance firm performance (Bartel et al., 2007). Although our company dataset does not include direct measurements of new technologies, we perform a heterogeneity analysis by sector classification to provide indirect evidence for this channel.

Our sample adheres to the Standard Industrial Classification (SIC03) used in the UK, dividing the sample into eight industry categories: Production, Construction, Catering, Motor Trade, Retail, Wholesale, Property, and Other Services. According to the UK's Office for National Statistics (ONS), 30% of our sample is from the manufacturing sector, while another 40% is from the service sector.

Specifically, we estimate the following modification of equation (5.1):

$$Y_{ijt} = a + \beta_1 Z_{jt} + \beta_2 Z_{jt} * \text{Sector} + \text{Sector} + \delta X_{it} + \sigma \text{X}_{\text{jt}} + \alpha_i + LA_j + Sector_p + Year_t + \epsilon_{ijt} \quad (5.1.2)$$

Where Sector represents the sector group of the firm industry. We use the production sector as our base reference group. The rest of variables are the same as our baseline regression model (5.1)

Firm locations

We further investigated the impact of urbanization and remoteness on the differential impact of ADSL access. Kandilov and Renkow (2010) found that areas close to large cities with dense populations primarily drive the economic impacts of broadband. In contrast, Lendle et al. (2016) support the "death of distance" theory, which suggests that reduced transportation and communication costs facilitated by information technology render Internet transactions independent of business locations, thus substituting for urban concentration. Fabritz (2013) noted that the positive employment outcomes of broadband adoption in Germany are more pronounced in remote regions. However, Canzian et al. (2019) found no evidence of variability in broadband adoption based on population density or remoteness. DeStefano et al. (2023) highlighted that broadband policies could significantly benefit rural businesses, especially in knowledge-intensive sectors.

Urban enterprises, being close to supplier networks and customers, experience only marginal reductions in communication costs from Internet access. Rural businesses, on the other hand, gain substantially as they can connect with distant suppliers via the Internet. Urban suppliers would benefit just as well as they can connect with other suppliers in other urban areas. Therefore, we hypothesize that rural firms should be more influenced by broadband infrastructure.

To test this hypothesis, we use the Rural/Urban 2004 classification at the Lower Layer Super Output Areas (LSOAs) level to categorize firms based on their location. In our sample, 60% of the firms are urban, while the remaining 40% are rural.

Specifically, we estimate the following modification of equation (5.1):

$$Y_{ijt} = a + \beta_1 Z_{jt} + \beta_2 Z_{jt} * \text{Urban} + \text{Urban} + \delta X_{it} + \sigma \text{X}_{\text{jt}} + \alpha_i + LA_j + Sector_\rho + Year_t + \epsilon_{ijt} \quad (5.1.3)$$

Where Urban indicates whether the firm is located in an urban area. We use urban areas as our base reference group. The rest of the variables are the same as our baseline regression model (5.1)

Heterogeneity Results

The question we attempt to answer in this section is whether factors such as the firm size, industrial sector, and degree of urbanization are related to the extent to which firms benefit from ADSL accessibility.

Firm size

It is currently unclear whether Broadband infrastructure has a greater impact on small businesses or large enterprises. Previous research (DeStefano et al, 2018) indicates that small companies are more advantageous in obtaining the benefits of information and communication technology (ICT). However, based on our balanced panel regression result, it is evident that well-performing or large companies often achieve higher returns. Moreover, SMEs (small and medium-sized enterprises) in the UK account for 99.9% of the business population (UK Government,2023). Therefore, it is essential to conduct a heterogeneity analysis based on firm size.

Table 5.4.3. Tabulation of firm size

Firm size	Freq.	Per cent	Cum.
Median	44337	21.16	21.16
Small	141476	67.52	88.68
Large	23714	11.32	100.00
Total	209527	100.00	

According to the classification standards (UK government,2023), we define companies with fewer than 50 employees as small firms, those with 50 to 250 employees as medium firms, and those with more than 250 employees as large firms. Table 5.4.3 provides the tabulation of firm size; small firms account for 67%, medium-sized firms for 20%, and large firms for 10%.

Table 5.4.4 reports regression results using small, medium, and large firms, with medium-sized firms serving as the reference group. Firm size categories defined by initial employment levels. The baseline coefficient for the Broadband Access Index therefore reflects the effect on medium-sized firms. For this group, we find a weakly significant negative effect on turnover (–0.0397 in Column 1), while the coefficients on employment and productivity indicators are small and insignificant (Columns 2–5). This suggests that, for medium-sized firms, broadband access alone does not translate into measurable performance improvements.

In contrast, the interaction terms reveal clear patterns of heterogeneity. For small firms, broadband access leads to a 7.0% increase in turnover and a 17.8% increase in employment, indicating that these firms expand revenues and headcount following broadband rollout. However, both measures of labour productivity decline significantly, with gross value added per worker falling by 20.2% and turnover per worker decreasing by 10.6%, while the effect on overall GVA remains insignificant. This suggests that growth in small firms is largely labour-intensive rather than efficiency-driven. A plausible interpretation is that smaller firms lack sufficient absorptive capacity and organisational resources to translate digital infrastructure into productivity gains, leading instead to "extensive growth" through labour expansion. Consistent with this view, the dynamic employment effects observed in the event-study analysis are predominantly driven by small firms, underscoring their role in shaping the aggregate employment response to broadband availability. And we also show the evidence that firm exits rate is increases in chapter 4, the lack of efficiency gains leaves them more vulnerable to competitive pressures

Table 5.4.4 Heterogeneity Analysis in Firm Size

	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	**Log of Firm Employment**	**Log of Firm GVA**	**Productivity (GVA)**	**Productivity (Turnover)**
Broadband Access Index	-0.0397*	-0.00732	0.00687	0.0277	-0.0300
	(0.0213)	(0.0112)	(0.0182)	(0.0188)	(0.0221)
Broadband Access IndexXSmall	0.0699**	0.178***	-0.0139	-0.202***	-0.106***
	(0.0291)	(0.0166)	(0.0230)	(0.0241)	(0.0320)
Broadband Access IndexXLarge	0.0595**	-0.0838***	-0.0238	0.0654***	0.141***
	(0.0275)	(0.0136)	(0.0232)	(0.0248)	(0.0277)
Foreign	0.0302***	0.00959**	0.000251	-0.0111	0.0203**
	(0.00916)	(0.00412)	(0.00805)	(0.00854)	(0.00917)
Age	0.0200***	0.00795***	0.00108	-0.00591**	0.0124***
	(0.00397)	(0.00161)	(0.00244)	(0.00248)	(0.00390)
Multi-plant	0.129***	0.278***	0.0959***	-0.176***	-0.149***
	(0.0157)	(0.0105)	(0.0140)	(0.0170)	(0.0161)
Lntele	0.0374***	0.0467***	0.0504***	0.00348	-0.00952
	(0.00577)	(0.00373)	(0.00752)	(0.00715)	(0.00593)
Constant	7.435***	3.839***	7.324***	3.508***	3.589***
	(0.182)	(0.0542)	(0.0853)	(0.0923)	(0.154)
Observations	93,779	94,378	79,436	79,431	93,773
R-squared	0.946	0.979	0.956	0.839	0.882
GDPControl	YES	YES	YES	YES	YES
FirmFE	YES	YES	YES	YES	YES
YearFE					
DistrictFE	YES	YES	YES	YES	YES
Cluster	District	District	District	District	District
r2_within	0.00727	0.0547	0.00596	0.00724	0.00555
District_number	377	377	377	377	377
SectorFE					
YearFEXsectorFE	YES	YES	YES	YES	YES

Note: Robust standard errors in parentheses, adjusted for clustering at the district level. We included constant terms.The base group is medium level firm *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Observation dropped in 3, 4 because lack of GVA data.

In contrast, large firms respond in a productivity-enhancing manner. Broadband access leads to a 6.0% increase in turnover, accompanied by an 8.4% reduction in employment and simultaneous increases in both measures of labour productivity. Specifically, labour productivity rises by 6.5% and turnover per worker increases by 14.1%. This pattern suggests that large firms are better positioned to leverage broadband adoption to rationalise labour use and achieve efficiency gains, potentially through automation, digital integration, and complementary investments in human and organisational capital. Such findings align with the broader ICT literature, which highlights that productivity returns from general-purpose technologies depend critically on complementary investments. (Bresnahan and Trajtenberg, 1995; Brynjolfsson and Hitt, 2000; Akerman et al., 2015).

Firm sector

In this section, we attempt to understand better the mechanisms at play by documenting the heterogeneity across sectors. According to the UK Sector classification standards(ONS,2023), companies have 8 sectors: production, Construction, Catering, Motor Trader, Retail, Wholesale, Property and Other Services. Note that the Other Services sector covers most of the business services; the 2 digital sic code (03) is from 60 to 93, such as Information and communications, Financial services, and professional services. Production not only includes manufacturing but also includes agriculture and mining and elector/gas and water supply, but their proportion is very low, accounting for only 5% of the production observations. Previous evidence from Bloom et al. (2014), DeStefano et al. (2020) and Malgouyres et al.(2021) have shown heterogeneity in the effects of ICT across industries. Using Model (5.1.2), we interact with a sector dummy variable representing industrial sector firms (Production being the reference category) to derive interaction values for different sectors.

Table 5.4.5 reveals substantial variation across sectors, with the production sector serving as the reference group. For production firms, the coefficients on broadband availability are consistently small and insignificant, indicating limited direct impact. By contrast, sectoral interaction terms display distinct heterogeneity. In the catering sector, broadband availability is associated with significant employment gains (+0.106), but this expansion is accompanied by a sharp decline in labour productivity (–0.202), suggesting labour-intensive growth. Retail firms exhibit a similar pattern, with broadband driving employment growth (+0.087) without corresponding productivity improvements, consistent with the increased labour requirements of online platforms and fulfilment activities.

Table 5.4.5 Heterogeneity Analysis in Firm Sector

	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	Log of Firm Employment	Log of Firm GVA	Productivity (GVA)	Productivity (Turnover)
Broadband Access Index	-0.00209	-0.0164	-0.0127	0.00197	0.0160
	(0.0262)	(0.0132)	(0.0203)	(0.0192)	(0.0260)
CaterXBroadband Access Index	-0.0238	0.106**			-0.130*
	(0.0914)	(0.0527)			(0.0684)
ConstructionXBroadband Access Index	0.0323	0.0319	-0.00627	-0.0331	-0.000256
	(0.108)	(0.0526)	(0.0609)	(0.0740)	(0.0986)
Motor tradeXBroadband Access Index	-0.0246	-0.0260	0.114*	0.151**	-6.52e-05
	(0.0511)	(0.0364)	(0.0690)	(0.0747)	(0.0584)
PropertyXBroadband Access Index	-0.212	-0.124*	0.0722	0.166	-0.0933
	(0.212)	(0.0637)	(0.106)	(0.117)	(0.225)
RetailXBroadband Access Index	0.00181	0.0868**			-0.0866*
	(0.0425)	(0.0354)			(0.0447)
ServicesXBroadband Access Index	0.00309	0.0590***	0.0419	-0.00386	-0.0545
	(0.0438)	(0.0194)	(0.0303)	(0.0319)	(0.0443)
WholesaleXBroadband Access Index	0.0153	-0.0141	-0.0794	-0.0630	0.0302
	(0.0430)	(0.0263)	(0.0484)	(0.0479)	(0.0452)
Foreign	0.0305***	0.00861**	-7.76e-05	-0.0101	0.0216**
	(0.00916)	(0.00409)	(0.00806)	(0.00856)	(0.00918)
Age	0.0201***	0.00742***	0.000963	-0.00550**	0.0131***
	(0.00398)	(0.00163)	(0.00245)	(0.00248)	(0.00395)
Multi-plant	0.128***	0.276***	0.0963***	-0.173***	-0.148***
	(0.0158)	(0.0107)	(0.0139)	(0.0171)	(0.0162)
Lntele	0.0374***	0.0473***	0.0502***	0.00251	-0.0101*
	(0.00578)	(0.00378)	(0.00752)	(0.00716)	(0.00593)
Constant	7.433***	3.880***	7.330***	3.469***	3.545***
	(0.185)	(0.0493)	(0.0858)	(0.0927)	(0.164)
Observations	93,779	94,378	79,436	79,431	93,773
R-squared	0.946	0.979	0.956	0.839	0.882
GDPControl	YES	YES	YES	YES	YES
FirmFE	YES	YES	YES	YES	YES
YearFE					
DistrictFE	YES	YES	YES	YES	YES
Cluster	District	District	District	District	District
R2_within	0.00715	0.0471	0.00624	0.00472	0.00398
District_number	377	377	377	377	377
SectorFE					
YearFEXsectorFE	YES	YES	YES	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The motor trade sector displays a contrasting trajectory. Broadband access leads to an 11.4% increase in GVA per worker and a 15.1% increase in labour productivity, suggesting that these firms integrate digital infrastructure into logistics and transactions in a way that enhances efficiency. In the service sector, broadband results in a 5.9% increase in employment, although no significant efficiency gains are observed. In the property sector, broadband leads to a 12.4% reduction in employment, accompanied by negative but statistically insignificant effects on turnover and productivity. Finally, sectors such as construction and wholesale show no significant responses across outcomes, suggesting either limited dependence on broadband or the presence of more complex adjustment channels.

Our results are consistent with Canzian et al. (2019), who find that broadband promotes growth in the service sector. We extend this evidence by showing that industries such as motor trade benefit even more strongly from broadband access. By contrast, unlike De Stefano et al. (2019) on the effects of ICT, we do not find significant impacts on production or manufacturing.

Firm urban/rural location

In this section, we attempt to understand better the mechanisms at play by documenting the heterogeneity in firm location (rural vs urban). Urban areas is our base group. The results in Table 5.4.6 suggest that broadband infrastructure may generate location-specific benefits. While the main effect of broadband access remains insignificant across all five outcome variables, the interaction term *Rural × Broadband Access Index* is positive and weak significant for turnover and labour productivity measured as turnover per worker (Columns 1 and 5). These findings imply that broadband may yield greater marginal revenue in rural areas, potentially by alleviating geographic constraints and expanding market access. However, no significant rural effects are observed for employment or GVA-based productivity, suggesting that these gains are more likely driven by output expansion.

Table 5.4.6 Heterogeneity Analysis in Firm urbanization

	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	Log of Firm Employment	Log of Firm GVA	Productivity (GVA)	Productivity (Turnover)
Broadband Access Index	-0.00353	0.00726	-0.00461	-0.000818	-0.00881
	(0.0174)	(0.00910)	(0.0154)	(0.0160)	(0.0172)
RuralXBroadband Access Index	0.145*	0.00161	0.0273	0.00840	0.147*
	(0.0781)	(0.0278)	(0.0534)	(0.0613)	(0.0761)
Foreign	0.0304***	0.00861**	5.04e-05	-0.00988	0.0214**
	(0.00916)	(0.00409)	(0.00805)	(0.00854)	(0.00915)
Age	0.0202***	0.00740***	0.00103	-0.00543**	0.0132***
	(0.00399)	(0.00163)	(0.00244)	(0.00248)	(0.00396)
Multi-plant	0.128***	0.276***	0.0960***	-0.174***	-0.149***
	(0.0157)	(0.0106)	(0.0140)	(0.0171)	(0.0162)
Lntele	0.0372***	0.0474***	0.0504***	0.00257	-0.0104*
	(0.00578)	(0.00378)	(0.00752)	(0.00715)	(0.00595)
Constant	7.432***	3.870***	7.324***	3.475***	3.555***
	(0.183)	(0.0517)	(0.0857)	(0.0910)	(0.157)
Observations	93,779	94,378	79,436	79,431	93,773
R-squared	0.946	0.979	0.956	0.839	0.882
GDPControl	YES	YES	YES	YES	YES
FirmFE	YES	YES	YES	YES	YES
YearFE					
DistrictFE	YES	YES	YES	YES	YES
Cluster	District	District	District	District	District
R2_within	0.00719	0.0464	0.00593	0.00446	0.00396
District_number	377	377	377	377	377
SectorFE					
YearFEXsectorFE	YES	YES	YES	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.5 Discussion

In this chapter, we employ TWFE model and staggered difference-in-differences design to estimate the impact of the unexpected rollout of ADSL broadband infrastructure in the UK by BT. This strategy enables us to better identify the causal effect of local broadband infrastructure from firms own ICT investment decisions. Firm performance is assessed along three dimensions, namely turnover, employment, and gross value added, together with two measures of labour productivity: gross value added per worker and turnover per worker.

Our findings challenge the dominant view in the literature that broadband infrastructure uniformly promotes firm performance and productivity. At the aggregate level, we detect no significant effects of broadband on turnover, GVA, or productivity, and only weak positive effects on employment. Event-study results further reveal that this positive effect strengthens gradually over time, reaching around a 5% increase in employment two years after broadband rollout. The central contribution of this chapter lies in highlighting the heterogeneous responses across firms and industries. Small firms expand employment and turnover after broadband access, but this growth is largely labour-intensive and accompanied by declining productivity, reflecting limited managerial and absorptive capacity. By contrast, large firms achieve efficiency-enhancing outcomes: they reduce employment while simultaneously increasing turnover and labour productivity, suggesting that they are better positioned to integrate broadband into organizational and technological upgrading. Sectoral patterns reinforce this heterogeneity: industries such as motor trade display stronger efficiency gains compared with labour-intensive services like catering and retail. These results explain why the baseline regressions show weak or insignificant average effects: positive and negative responses across firm types offset one another. More importantly, they demonstrate that broadband infrastructure is not a uniform productivity driver but an amplifier of existing firm capabilities.

From a policy perspective, our results highlight the importance of addressing the digital divide. The findings suggest that digital infrastructure rollout alone is insufficient to generate broad-based productivity gains. Instead, the benefits of broadband depend critically on firms' absorptive capacity, organisational capabilities, and complementary resources. While smaller firms often expand employment after gaining broadband access, their limited managerial and technological capacities constrain sustainable efficiency gains. In contrast, larger firms are better able to convert connectivity into operational efficiency, thereby widening performance gaps. This dynamic raises concerns that broadband infrastructure may exacerbate divides across firms, sectors, and regions.

Policy should therefore move beyond expanding fibre or next-generation networks to focus on bridging capability gaps, for instance, by strengthening SMEs' digital skills, supporting complementary technological investment, and encouraging organizational upgrading. Programmes such as the UK's Digital Skills Partnership and Made Smarter offer models of how infrastructure policy can be combined with capability-building. Ultimately, the effectiveness of broadband investment depends not only on the speed and coverage of rollout but also on ensuring that firms have the resources and skills to harness digital infrastructure productively.

Chapter Six Broadband infrastructure and manufacturing servitisation

6.1. Introduction

There is increasing evidence that the share of manufacturing in developed countries is declining, along with the overall contribution to production and employment. On the other hand, the share of the service sector is expanding. Economic analysis typically views the decline in manufacturing as a shift of resources toward the service sector (Pilat et al., 2006). At the same time, during this industrial shift, more and more studies have found that manufacturing firms are increasingly providing services, offering a fusion of products and services. This phenomenon, known as servitisation, has been observed in both developed and developing economies (Neely et al., 2011). In fact, some companies have found this to be the most effective way to open doors to future business (Wise and Baumgartner, 2000). A practical example of servitisation is Toyota's European subsidiary, a truck manufacturer that has significantly enhanced the role of services in its business. IBM is transforming into a cognitive solutions and cloud platform company, and the leading electronic computer company; Apple, has introduced ecosystems like iTunes. (Raddats et al., 2017). However, not all companies benefit from this transition. Some studies have shown that firms investing in servitisation did not achieve the expected returns, leading to their exit from the market (Gebauer et al., 2005)

Since the term 'servitisation' was introduced by Vandermerwe and Rada in 1988, it has become a focus for many scholars. Many researchers believe that services are more profitable than products, as service profit margins are generally higher than those of products (Oliva and Kallenberg, 2003). Additionally, servitisation allows companies to differentiate their products from those of competitors, leading to increased profits (Baines et al., 2009). This period also corresponds with the explosive development of information and communication technology (ICT) innovations, particularly the widespread adoption of broadband infrastructure and the rapid spread of the Internet in the global economy. Initially, information digital technological advancements and servitisation were seen as two separate directions for manufacturing firms. However, it is only recently that research has begun to recognize the interaction between digital technological advancements and servitisation. A large body of qualitative research suggests that advancements in information technology can make a firm's servitisation strategy more successful. For example, Internet technology overcomes traditional geographical limitations, allowing for the interconnection of customers, internal data, and external entities, thereby maximizing the integration of different resources and enabling firms to better leverage servitisation to gain profits. (Leeflang et al., 2014; Gebauer et al., 2021; Harrmann et al., 2023)

However, most of the available evidence is based on firm-level case studies or limited samples of relatively large companies. The advantage of these methods lies in their ability to provide an in-depth analysis of the business strategies and channels through which servitisation operates. However, they lack the empirical evidence from quantitative analysis. Therefore, we provide quantitative evidence to address this gap. In contrast to the literature that considers internal strategies like information technology as subjective choices by firms for digital transformation, our study offers evidence of the impact of exogenous infrastructure development on internal servitisation within firms. Our research hypothesizes that the development of external broadband infrastructure has a positive impact on the enhancement of servitisation within firms.

Due to the endogeneity of information technology, identifying the causal effect of technology on firm-level servitisation is usually challenging. Therefore, we leveraged data and the context from the UK, which allows us to make progress in identifying the causal relationship between technology and firm-level service activities. In terms of data, we collected a new dataset on city-level broadband Internet availability during the period from 1997 to 2002 and combined it with information on firms' service activities. Regarding the context, we utilized the gradual rollout of broadband Internet in the UK. This setting provides a natural basis for examining how the availability of broadband infrastructure affects firms' internal service activities. Additionally, due to the presence of a large number of zero values in the data, we used the Poisson Pseudo Maximum Likelihood method in this chapter to estimate the impact of broadband Internet from 1997 to 2002 on the internal service revenues of UK firms. We further combined this analysis with firms' internal R&D data to explore the mechanism of the impact of broadband infrastructure.

Our research finds that local broadband Internet access leads to a significant increase in the ratio of service revenue to goods revenue at the firm level, which supports our hypothesis that broadband infrastructure has a positive effect on firm servitisation. After excluding the impact of foreign service revenue, our results show that the service ratio still increases. Furthermore, when interacting with internal firm research expenditure, we find that firms with higher research levels are better able to leverage the effects of infrastructure. To the best of our knowledge, we are the first to conduct a quantitative study on the impact of external information infrastructure on firm servitisation, which has implications for advancing firms' digital strategies. However, our paper has limitations. When we consider the pure impact of service revenue, the results indicate a lack of robustness.

The chapter is organized as follows. Section 6.1: Introduction. Section 6.2: Data section. This section covers the definition of company service revenue and goods revenue, data collection, and a descriptive summary. The primary data source is the Annual Respondents Database (ARD), and our regression sample spans from 1997 to 2002.Section 6.3: Methodology. We discuss our methodology. Section 6.4: Results. This section presents our baseline findings, robustness checks and heterogeneity analysis. Section 6.5: Conclusion We conclude with a summary of our results and their implications.

6.2. Data

To test the hypothesis that broadband infrastructure has a positive impact on the servitisation within firms. In this section, we will describe how we measure servitisation and local broadband Internet and discuss our selection of control variables for the firms.

Dependent Variables

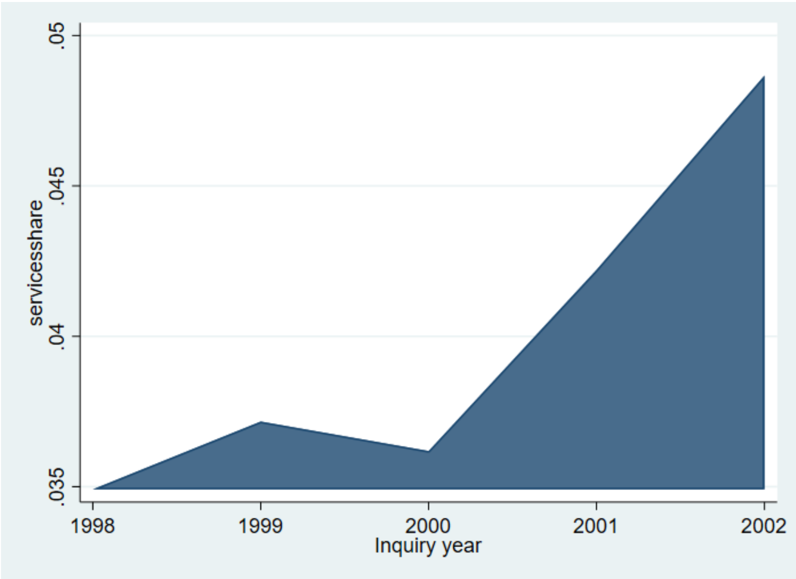
We use the ratio of services revenue to goods revenue as our servitisation index. The same as previous chapter, we collect service revenue and goods revenue from the Annual Respondents Database (ARD), which provides firm-level survey data from 1997 to 2002. The ARD is a survey-based dataset that samples approximately 50,000 firms each year, resulting in an unbalanced panel due to the sampling method. These data are obtained through random sampling. Our primary variables of interest are the total value of the service provision and the total value of goods produced by firms. Unfortunately, the ARD only contains the total value of the service provision (i.e., it does not provide the specific service type), preventing us from providing a detailed segmentation of the entire service provision.

In our analysis, we focus on the manufacturing sector. Although firms may change their industry classification after registering their initial sector, such changes are rare in practice, even if the firms' output mix changes significantly. We include all firms that reported their initial activity in manufacturing in the first year they appear in the data as our sample.[8] We also considered companies that might change their geographic location. Although this is uncommon in the manufacturing sector, we still excluded companies that relocated to different regions from our sample.

Figure 6.1 present the annual evolution of the share of service revenue in total revenue for the UK manufacturing firms from 1998 to 2002. There is a rapid increase in the share after 2000. At the individual firm level, the shift towards service production is also evident.

[8] 2 digital SIC03 code: 15-37

Figure 6.1. Share of Services in UK Manufacturing (1997–2002)



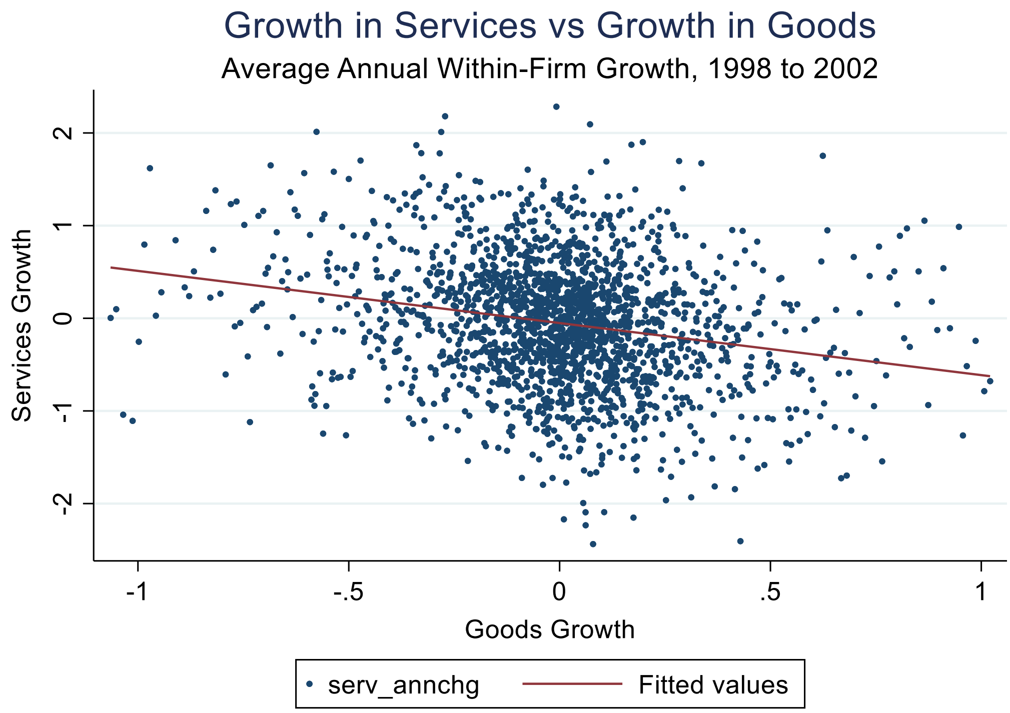
Note: The figure shows the ratio of services revenues to total revenues in the UK manufacturing sector over the period 1997 to 2002.

Figure 6.2 presents a scatterplot of average annual growth in services provision versus goods production within UK manufacturing firms over the period 1998 to 2002. Each dot represents a firm-level observation, with growth rates calculated based on within-firm changes in the logarithm of goods and services output. Specifically, for each firm, we compute the average annual change in log output between adjacent years during the period 1998–2002. This construction ensures that the observed negative relationship reflects a reallocation of output within the same firm, rather than a compositional shift across sectors or firm types.

The figure reveals a significant negative correlation between the two dimensions of output growth. This implies that, on average, firms that expanded their service offerings tended to contract or grow less in their goods production, and vice versa. Importantly, this relationship emerges within firms, not merely across sectors or firm types.

This finding provides micro-level evidence of servitisation in the UK manufacturing sector, a structural shift in which firms reallocate internal resources from tangible production to intangible, service-based activities. The negative slope reflects a trade-off: instead of simply growing both goods and services together, many firms appear to reposition their core business model, gradually transitioning from product-centric to service-enhanced operations.

Figure 6.2. Average Annual Within-Firm Growth in Goods versus Services[9]



Independent Variable

Broadband access index. Same as chapter four, the broadband infrastructure access index is based on data from Ofcom and Point-Topic.com. It covers all of the UK-level district broadband access index from 1999 to 2002. We also drop the two districts around Hull areas, whose broadband infrastructure is independently controlled by KCOM. And we also drop the North Ireland area.

Control Variable

Firm specific condition

The control variables at the firm level are also derived from ARD. These variables include the firm's age, whether the company has multiple plants, whether the company is a foreign enterprise, the company's total wage expenditure, and the company's labour productivity. Considering the company's own investment in information technology, we also include the company's communication technology costs. In our heterogeneity analysis, we considered the company's total R&D expenditure data from Business Enterprise Research and Development

[9] We also provide the regression results of goods and services. The coefficient is -0.58 with a standard error of 0.05.

(BERD) dataset to obtain the company's R&D intensity.[10]

Local Economic Conditions

The economic conditions of the region can also impact the operation of enterprises. We used the district's GDP per capita to measure the regional economic conditions. While we acknowledge that contemporaneous GDP may be endogenous to firm outcomes. We view this specification as a reasonable trade-off to avoid omitting important time-varying local economic shocks. The results in this chapter should therefore be interpreted with caution, and we explicitly treat the GDP variable as a potentially endogenous control.

Sample Selection and Summary Statistics

In the ARDx dataset, we only consider the firms which are in the Manufacturing section. Additionally, we excluded two districts from Northern Ireland and the Hull area due to broadband data limitations. Our final sample includes 8606 firms and 55040 observations from 1998 to 2002. Table 6.3 provide the summary statistics of the key variables from the estimation sample. And we combining the ARDx and BERD through the Inter-Departmental Business Register reference(IDBR) numbers to collect the R&D information. It is noted that BERD only have 9335 observations to match the ARDx IDBR code. So when we consider heterogeneity analysis, the number of sample is reduced due to the smaller sample of firms drawn for the BERD. The table 6.3. shows that the average turnover revenue in the sample is 22446, with a standard deviation of 145307. Similarly, goods revenue is 16553, with a standard deviation of 89448, while services revenue is 676, with a standard deviation of 11184. It is noteworthy that the median value for service revenue is 0, which suggests that a significant portion of the companies in the sample likely do not have service sales. Additionally, the average R&D expenditure is only 1256, accounting for just 5% of turnover, with a median value of only 106, which may imply that many firms do not have R&D expenditures.

[10] Business Enterprise Research and Development (BERD): we used BERD to collec the firm level research and development expenditure cost. BERD provide the firm level intram-expenditure and it also provide firm level high science employee number and high techonology employee number.

Table 6.3. Summary statistics

	Mean	Std. Dev.	Median	N
Year	1999.97	1.41	2000	55040
No of local units	1.82	4.69	1	55040
Foreign	.18	.38	0	55040
Total employment Costs(£000)	3885.88	15139.04	944	55040
Sales of goods (£000)	16553.23	89448.7	2567	53608
Age	16.62	8.63	16	54163
Capstock	11742.87	61753.39	1911.23	55040
Services provided(£000)	676.11	11184.64	0	54009
LnGDP	8.04	.74	7.98	55040
Lnpopulation	12.14	.64	12.1	55040
Broadband access index	.18	.29	0	55040
Employment	167.18	501.94	51	55040
Turnover(£000)	22446.18	145307.22	3329	55040
R&D Expenditure(£000)	1256.71	11292.63	106.02	9335

Note: R&D expenditure is from the Business Enterprise Research and Development (BERD) dataset, which only have limited observations.

6.3. Empirical Method

We employ a Two-way fixed effect model (TWFE) approach to design model specifications to examine the relationship between firm servitisation and broadband infrastructure. The model specifications are as follows:

$$Y_{ijt} = a + \beta Z_{jt} + \sigma_1 \mathrm{X}_{\mathrm{jt}} + \sigma_2 \mathrm{X}_{\mathrm{jt}}\ \alpha_i + LA_j + Year_t + \mathrm{SIC2}_{\mathrm{ijt}} + \epsilon_{jt} \ (6.1)$$

where Z_{jt} refers to the continuous index form of broadband access index at local authority j at time t from equation (2.1). Y_{ijt} represents outcome variable such the revenue from services as a share of total revenue, the share of services revenue to goods revenue, the goods output and services output. The output variable definition is from Breinlich et al., (2018), this allows us to evaluate whether changes in relative revenues are driven by goods, services, or both. η_i , LA_j $and\ year_t$ represent the firm level fixed effect, district level fixed effect and year fixed effect. X_{ijt} represent the firm level control variables, like firm age; firm foreign ownership; whether firms have multiplant, the cost of wage; labour productivity and the cost of telecommunication. X_{jt} represent local economic gdp per captia. Add control variables help us to reduce the threat of ommited variable bias and increase the precision of estimates. We also control sector 2-digital level fixed effect (sic03) rather sector level, because we only consider the manufacture industry firms. Cluster standard errors at district level. The main coefficient of interest is β_1, indicates whether firms react to local broadband access by increaseing services output relative to goods output ($\beta_1 > 0$) or by reducing it ($\beta_1 < 0$).

6.4. Empirical Result

In this session, we employed the TWFE model to estimate the effect of broadband availability on firm services performance. And we explore the robustness check and heterogeneity analysis.

6.4.1 Baseline Regression

Table 6.4.1 to Table 6.4.4 show the regression results with Z_{jt}, broadband access index. Column 1 shows estimates only control firm fixed effect, district fixed effect and year fixed effect. Column 2 shows estimates add the control variables such as foreign ownership; firm age; whether have multi-local units/plants, the cost of telecom and the local GDP per capita and firm wages and firm productivity. Column 3 add the SIC 2digital level fixed effect. And column 4 adds the sic2 digital level sector interact with year fixed effect.

Table 6.4.1 examines whether broadband access influences the share of service revenue in total firm revenue, as a proxy for servitisation. Across all four model specifications, the coefficient on the broadband access index is consistently positive but insignificant. This suggests that, on average, greater broadband access does not significantly shift the composition of firm revenue toward services among manufacturing firms.

In Table 6.4.2, the dependent variable is the ratio of service revenue to goods revenue, offering a more direct measure of revenue rebalancing within firms. While the broadband access coefficient is large in magnitude (e.g., 4.35 to 4.78), it remains insignificant across all specifications due to large standard errors. This implies that although there is variation in service/goods ratios, it is not explained by broadband access.

Table 6.4.1 Ratio of service/total revenue as Dependent Variable

	(1)	(2)	(3)	(4)
	Ratio of service/total revenue	**Ratio of service/total revenue**	**Ratio of service/total revenue**	**Ratio of service/total revenue**
Broadband access index	0.00325	0.00252	0.00247	0.00124
	(0.00300)	(0.00299)	(0.00300)	(0.00297)
Foreign		0.000789	0.000944	0.000395
		(0.00165)	(0.00165)	(0.00161)
Age		6.77e-05	8.35e-05	0.000197
		(0.000289)	(0.000291)	(0.000305)
Multi-plant		0.00299	0.00272	0.00277
		(0.00272)	(0.00273)	(0.00271)
Lntele		0.00717***	0.00705***	0.00683***
		(0.00161)	(0.00160)	(0.00160)
Lngdper		0.0257	0.0257	0.0229
		(0.0186)	(0.0186)	(0.0178)
Lnwage		-0.000948	-0.00100	-0.000792
		(0.00305)	(0.00305)	(0.00306)
Lnlabour		0.00106	0.00101	0.00128
		(0.00115)	(0.00115)	(0.00120)
Constant	0.0245***	0.105	0.106	0.0914
	(0.000506)	(0.0769)	(0.0769)	(0.0736)
Observations	35,633	34,562	34,562	34,561
R-squared	0.866	0.865	0.866	0.868
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
R2_within	8.94e-05	0.00414	0.00398	0.00371
Distrct_number	376	376	376	376
YearFEXSIC2FE				YES
SIC2FE			YES	

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6.4.2 Ratio of service/goods revenue as Dependent Variable

	(1)	(2)	(3)	(4)
	Ratio of service/goods revenue	Ratio of service/goods revenue	Ratio of service/goods revenue	Ratio of service/goods revenue
Broadband access index	4.352	4.771	4.782	3.737
	(4.494)	(4.775)	(4.787)	(3.753)
Foreign		0.113	0.112	0.0388
		(0.109)	(0.109)	(0.102)
Age		-0.0110	-0.0108	-0.00247
		(0.0109)	(0.0109)	(0.0136)
Multi-plant		0.0427	0.0416	0.190
		(0.117)	(0.117)	(0.191)
Lntele		-0.0888	-0.0883	-0.137
		(0.250)	(0.250)	(0.291)
Lngdper		-22.30	-22.32	-24.21
		(15.77)	(15.80)	(17.12)
Lnwage		1.933	1.936	2.026
		(2.342)	(2.347)	(2.488)
Lnlabour		-0.610	-0.611	-0.599
		(0.912)	(0.913)	(0.930)
Constant	-0.368	-95.54	-95.67	-103.6
	(0.756)	(68.07)	(68.19)	(73.94)
Observations	35,356	34,338	34,338	34,337
R-squared	0.490	0.490	0.490	0.491
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
R2_within	0.000337	0.000573	0.000574	0.000451
Distrct_number	376	376	376	376
YearFEXSIC2FE				YES
SIC2FE			YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6.4.3 investigates whether broadband access is associated with changes in the absolute level of service revenue (in logs form). The coefficient on broadband is negative but insignificant in the first three specifications and turns positive in the fourth, again insignificant. Interestingly, other variables such as telecom usage and firm size are strong positive predictors of service revenue, aligning with expectations that ICT capacity support service expansion. However, the lack of a significant broadband effect suggests that either broadband penetration is not a key driver of service output.

Table 6.4.3 The log of service revenue as Dependent Variable

	(1)	(2)	(3)	(4)
	Log of services	Log of services	Log of services	Log of services
Broadband access index	-0.0141	-0.00810	-0.00504	0.124
	(0.113)	(0.114)	(0.114)	(0.111)
Foreign		-0.00463	0.000893	0.0307
		(0.0652)	(0.0648)	(0.0632)
Age		-0.00934	-0.00801	-0.0113
		(0.0172)	(0.0174)	(0.0185)
Multi-plant		0.0397	0.0332	-0.0408
		(0.110)	(0.107)	(0.100)
Lntele		0.573***	0.578***	0.594***
		(0.0538)	(0.0543)	(0.0551)
Lngdper		0.225	0.0455	0.135
		(0.925)	(0.933)	(0.920)
Lnwage		-0.00366	0.00231	-0.000904
		(0.104)	(0.103)	(0.101)
Lnlabour		0.243***	0.249***	0.278***
		(0.0502)	(0.0498)	(0.0505)
Constant	3.409***	1.978	1.170	1.454
	(0.0195)	(3.812)	(3.842)	(3.812)
Observations	11,278	10,980	10,980	10,978
R-squared	0.859	0.864	0.864	0.877
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
R2_within	2.57e-06	0.0352	0.0355	0.0398
Distrct_number	372	372	372	372
YearFEXSIC2FE				YES
SIC2FE			YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In contrast to service revenue, Table 6.4.4 shows a significant negative effect of broadband access on goods revenue in three of the four specifications. This finding implicates that broadband may reduce reliance on physical goods output, potentially due to operational restructuring, process digitization, or substitution effects. The drop in significance in the fourth model (which includes SIC 2digital level-year fixed effects) indicates some sensitivity to model specification, but the pattern is broadly robust.

Table 6.4.4 The log of service revenue as Dependent Variable

	(1)	(2)	(3)	(4)
	Log of Goods	**Log of Goods**	**Log of Goods**	**Log of Goods**
Broadband access index	-0.0311*	-0.0292**	-0.0282**	-0.0218
	(0.0163)	(0.0143)	(0.0143)	(0.0144)
Foreign		0.00318	0.00337	0.00226
		(0.00844)	(0.00841)	(0.00850)
Age		0.00406***	0.00421***	0.00322**
		(0.00144)	(0.00149)	(0.00152)
Multi-plant		0.104***	0.102***	0.0996***
		(0.0132)	(0.0133)	(0.0132)
Lntele		0.139***	0.140***	0.140***
		(0.00776)	(0.00782)	(0.00789)
Lngdper		-0.0123	-0.00811	-0.0257
		(0.116)	(0.116)	(0.113)
Lnwage		0.0497***	0.0499***	0.0486***
		(0.0182)	(0.0182)	(0.0179)
Lnlabour		0.179***	0.179***	0.176***
		(0.0106)	(0.0105)	(0.0104)
Constantc	8.605***	7.305***	7.318***	7.277***
	(0.00273)	(0.479)	(0.480)	(0.467)
Observations	35,356	34,338	34,338	34,337
R-squared	0.975	0.979	0.979	0.979
FirmFE	YES	YES	YES	YES
YearFE	YES	YES	YES	
DistrictFE	YES	YES	YES	YES
R2_within	0.000226	0.101	0.102	0.100
Distrct_number	376	376	376	376
YearFEXSIC2FE				YES
SIC2FE			YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results across Tables 6.4.1–6.4.4 suggest that broadband access does not significantly raise service revenue or its share, but it does appear to reduce goods revenue, implying a relative rebalancing of output rather than an expansion of the service side. Therefore, the servitisation process might not be driven by increased service sales, but rather by a decline in goods-focused activities, potentially due to reallocation of resources or changing market strategies under digital transition. However, it is also plausible that the observed patterns stem from limitations in the data structure. In our sample, a substantial share of manufacturing firms reports zero service revenue, resulting in a large mass of observations with a service ratio of zero. This could bias results toward zero or obscure meaningful effects among firms that actively engage in service provision. To address this issue, in our robustness section, we re-estimate the core specifications using the Pseudo-Poisson Maximum Likelihood (PPML) estimator.

6.4.2 Robustness checks

In this session, we conduct three robustness checks. (a) using an alternative estimation method. (b) using the ratio of services to total revenue. (c) considering domestic services revenue only.

PPML method

In this section, we evaluate the effect of the broadband access index on the ratio of services output to goods output from Breinlich et al., (2018). Specifically, we the PPML (Poisson Pseudo Maximum Likelihood) estimation as our empirical method. The use of PPML estimation is based on two specific features of our data. First, there are many zero values in our services revenue, many firms in our sample do not provide services. Second, PPML helps regression over the skewed distribution of revenues across firms. The model specifications are as follows:

$$Y_{ijt} = \exp\left[a + \beta Z_{jt} + \sigma_1 X_{jt} + \sigma_2 X_{jt}\, \alpha_i + LA_j + Year_t + \mathrm{SIC2}_{ijt}\right] + \epsilon_{ijt} \quad (6.2)$$

Where Z_{jt} refers to the continuous index form of broadband access index at local authority j at time t. Y_{ijt} represents outcome variable such the revenue from services as a share of total revenue, the share of services revenue to goods revenue, the goods output and services output. η_i , LA_j and $year_t$ represent the firm level fixed effect, district level fixed effect and year fixed effect. X_{ijt} represent the firm level control variables, like firm age; firm foreign ownership; whether firms have multi-plants, the cost of wage; labour productivity and the cost of telecommunications. X_{jt} represent local economic gdp per captia. We also control sector 2-digital level fixed effect (sic03) rather sector level. Cluster standard errors at district level.

PPML results:

Table 6.4.5 reports results from specifications that capture different aspects of servitisation ratio: (1) the ratio of service to total revenue; (2) the ratio of service to goods revenue; (3) the level of service revenue; and (4) the level of goods revenue. All models include firm and district fixed effects as well as SIC02 × year interactions to control for industry-specific time trends.

In Column (1), the coefficient on the Broadband Access Index is positive but insignificant when the dependent variable is the ratio of service to total revenue. However, in Column (2), where the dependent variable is the ratio of service revenue to goods revenue, the coefficient becomes positive and highly significant (2.113). This suggests that broadband access is associated with a greater relative emphasis on service activities among firms that engage in both goods and service production.

Table 6.4.5 The PPML method on servitisation

	(1)	(2)	(3)	(4)
VARIABLES	**Ratio of service/total revenue**	**Ratio of service/Goods revenue**	**Services revenue**	**Goods revenue**
Broadband access index	0.0516	2.113***	-0.0328	-0.0188
	(0.0921)	(0.447)	(0.103)	(0.0341)
Foreign	-0.0121	-0.440*	0.0458	0.0104
	(0.0483)	(0.256)	(0.0662)	(0.0213)
Age	-0.00413	0.00764	0.00199	0.00462***
	(0.0104)	(0.0530)	(0.0114)	(0.00178)
Multi-plant	0.121	0.270	-0.344*	0.0641**
	(0.128)	(0.427)	(0.207)	(0.0311)
Lntele	0.180***	0.346**	0.154***	0.117***
	(0.0499)	(0.141)	(0.0507)	(0.0243)
Lngdper	1.072*	-9.838***	0.953	-0.0112
	(0.630)	(2.984)	(0.661)	(0.221)
Lnwage	-0.0184	2.346***	0.0365	-0.0407
	(0.0908)	(0.894)	(0.149)	(0.0290)
Lnlabour	0.0652	-1.002**	0.104	0.179***
	(0.0514)	(0.448)	(0.0666)	(0.0175)
Constant	1.979	-27.32***	13.13***	10.25***
	(2.467)	(9.253)	(2.595)	(0.897)
Observations	21,709	21,470	22,151	34,909
FirmFE	YES	YES	YES	YES
YearFE				
DistrictFE	YES	YES	YES	YES
District_number	374	374	375	376
YearFEXSIC2FE	YES	YES	YES	YES

Notes: PPML regressions. FE indicates fixed effects in the model. Sector Time trends are two-digit UK SIC industry time trends. Standard errors are clustered at the district level and are in parentheses. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Interestingly, the coefficients in Columns (3) and (4), where the dependent variables are service and goods revenues, are small and insignificant, indicating that broadband access does not affect the absolute magnitude of either component. Instead, broadband appears to influence the composition of revenue by promoting services relative to goods, rather than expanding overall business volume. The PPML results provide stronger evidence that broadband access increases the relative importance of services in manufacturing firms, particularly when compared with goods production.

Domestic services revenue in PPML model

As our PPML regression find that the ratio of services to goods revenues is positive with broadband access index. We further explore the ratio of services to goods revenues includes exports as well as domestic sales. Export revenues are affected by multilateral trade factors such as foreign trade barriers, and omitted variables may introduce some degree of bias into our conclusions. Therefore, we conducted a simple robustness check by examining only domestic revenue as a substitute, using the formula $(\frac{SR_{ijt}-SR_{ijt}(exports)}{GR_{ijt}})$ for total service revenue minus export service revenue. Unfortunately, we did not obtain data on goods export revenue, so we continue to use total goods revenues as our denominator. Table 6.4.7 shows the estimates of the broadband access index on the ratio of domestic services to goods revenue. When we use domestic services revenues as our dependent variable in Table 6.4.7 (columns 3–4), we obtain slightly smaller coefficient estimates in absolute terms on our local broadband estimator and significant at a 10% level. This suggests that the broadband–servitisation relationship is driven by domestic market demand rather than by export-oriented services.

Table 6.4.7 Domestic services revenue over goods output as dependent variable

	(1)	(2)	(3)
	Domestic services revenue over goods		
Broadband access index	0.925*	0.981*	0.395
	(0.535)	(0.548)	(0.403)
Foreign	-0.222*	-0.235**	-0.153
	(0.118)	(0.118)	(0.119)
Age	-0.0139	0.0141	-0.0141
	(0.0321)	(0.0222)	(0.0252)
Multi-plant	-0.539	-0.368	-0.376
	(0.515)	(0.443)	(0.381)
Lntele	0.368**	0.385**	0.309**
	(0.161)	(0.165)	(0.153)
Lngdper	0.300	0.341	0.0708
	(3.175)	(3.174)	(2.523)
Lnwage	0.575	0.576	0.218
	(0.414)	(0.415)	(0.367)
Lnlabour	-0.0629	-0.0732	0.169
	(0.197)	(0.198)	(0.183)
Constant	4.271	3.560	4.812
	(7.317)	(7.341)	(6.156)
Observations	14,475	14,471	14,468
Year FE	YES	YES	YES
District FE	YES	YES	YES
District_number	373	373	373
Firm FE	YES	YES	YES
YearFEXSIC2FE			YES
SIC2FE		YES	

Notes: PPML regressions. FE indicates fixed effects in the model. Sector Time trends are two-digit UK SIC industry time trends. Standard errors are clustered at the district level and are in parentheses. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Difference in Difference framework

The same as chapter 4, we utilize the DID model and event-study to assess the broadband effect on firm servitisation. Since we have no information on broadband adoption by the firms in our sample, the estimated effects represent intention-to-treat effects.

Traditional DiD Model:

$$Y_{jt} = a + \beta Treated_{jt} + \sigma X_{jt} + LA_j + Year_t + \epsilon_{jt} (6.3)$$

Where Y_{ijt} represents a servitisation variables in year t in district (Local Authority) LA_j. $Treated_{ijt}$ is an indicator for whether in year t, ADSL Broadband was activated at LA_j. X_{jt} are vector for District(LA) level controls. LA_j and $Year_t$ respect the district level (Local Authority) fixed effect and year fixed effect respectively. The district fixed effect captures all time-invariant sources of spatial variation, and the year fixed effect captures any time-specific influences that could affect the outcome. The error term ϵ_{jt} cluster at district level.

Event-Study model:

$$Y_{jt} = \sum_{d=-3}^{d=-1} \beta_d \times 1(t = d + t_{j0}) + \sum_{d=0}^{d=2} \beta_d \times 1(t = d + t_{j0}) + \sigma X_{jt} + LA_j + Year_t + \epsilon_{jt} \quad (6.4)$$

Where t_{j0} represent the year district experience ADSL treatment and term d represent the number of years away from ADSL broadband access treatment year. If d is negative, which means d years before the treatment year, if d is positive, it shows the d year after treatment year. We include a vector of 3 leads and 2 lags of broadband access which range from 3 periods before broadband access until 2 periods after broadband access. β_d represent the effect of broadband access/activation on firm entry/exits, d years away from broadband access/activation and it is the main coefficient of our interest.

Difference in Difference framework results

Table 6.4.8. The impact of broadband on traditional difference in difference model

	(1)	(2)	(3)	(4)
	Ratio of service/total revenue	**Ratio of service/Goods revenue**	**Services revenue**	**Goods revenue**
Treated	0.000922	1.040	0.0425	-0.00149
	(0.00152)	(1.346)	(0.0685)	(0.00863)
Foreign	0.000396	0.0359	0.0300	0.00229
	(0.00161)	(0.0980)	(0.0632)	(0.00851)
Age	0.000195	-0.00849	-0.0114	0.00326**
	(0.000305)	(0.0121)	(0.0186)	(0.00152)
Multi-plant	0.00277	0.227	-0.0390	0.0993***
	(0.00271)	(0.214)	(0.101)	(0.0132)
Lntele	0.00683***	-0.143	0.594***	0.140***
	(0.00160)	(0.292)	(0.0552)	(0.00788)
Lngdper	0.0229	-22.25	0.186	-0.0423
	(0.0174)	(15.66)	(0.923)	(0.111)
Lnwage	-0.000789	2.042	0.000617	0.0485***
	(0.00306)	(2.501)	(0.101)	(0.0179)
Lnlabour	0.00127	-0.605	0.277***	0.176***
	(0.00120)	(0.938)	(0.0506)	(0.0104)
Constant	0.0914	-95.01	1.677	7.205***
	(0.0717)	(67.40)	(3.825)	(0.461)
Observations	34,561	34,337	10,978	34,337
R-squared	0.868	0.491	0.877	0.979
FirmFE	YES	YES	YES	YES
Year FE				
District FE	YES	YES	YES	YES
District_number	0.00372	0.000268	0.0397	0.100
Firm FE	376	376	372	376
YearFEXSIC2 FE	YES	YES	YES	YES
SIC2FE				

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6.4.8. reports the Traditional DiD estimates across four outcome variables: the ratio of service to total revenue, the ratio of service to goods revenue, the log of service revenue. The coefficient on the Treated variable is insignificant across Columns (1)– (4), with magnitudes near zero in the service share and log (service revenue) specifications. These results suggest limited evidence of a significant broadband effect when using policy rollout DID treatment.

Figure 6.4.9 Event study effects of ADSL Broadband on Ratio of service/total revenue

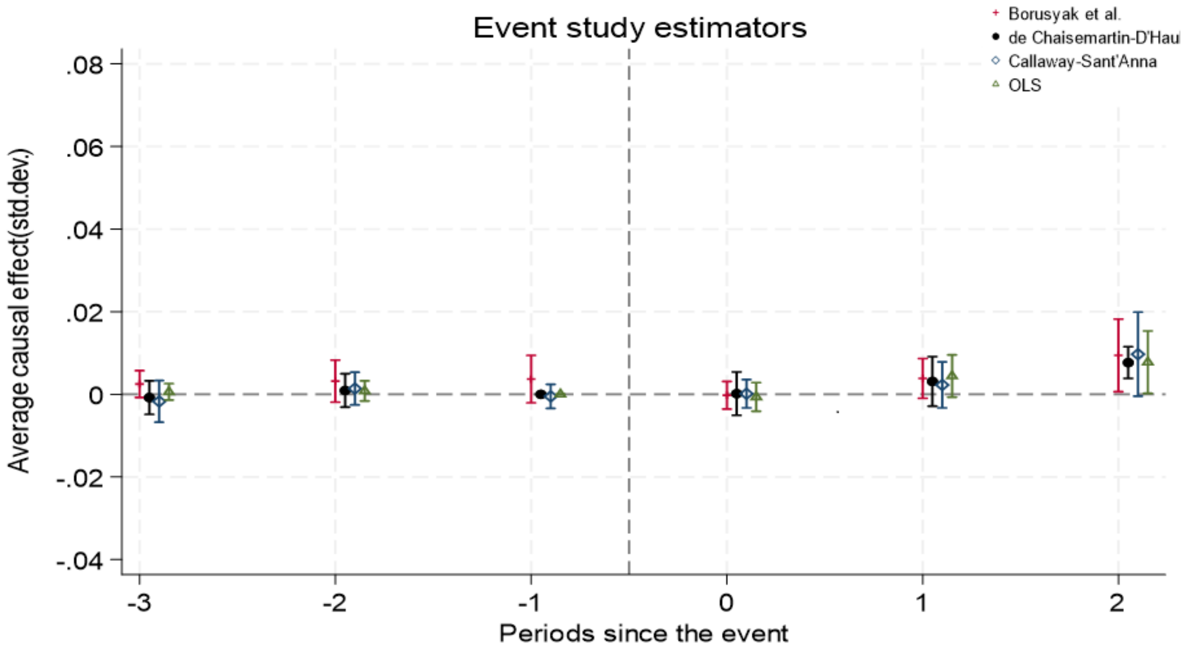


Figure 6.4.9 presents the dynamic effects of broadband rollout on the ratio of service to total revenue. All estimators exhibit pre-treatment coefficients that are in insignificant from zero, indicating no evidence of differential pre-trends. This supports the parallel trends assumption. Post-treatment, most estimates insignificantly remain close to zero, suggesting that broadband rollout had no immediate or short-run impact on the degree of servitisation among manufacturing firms within the two-year observation window.

Figure 6.4.10 Event study effects of ADSL Broadband on Ratio of service/total revenue

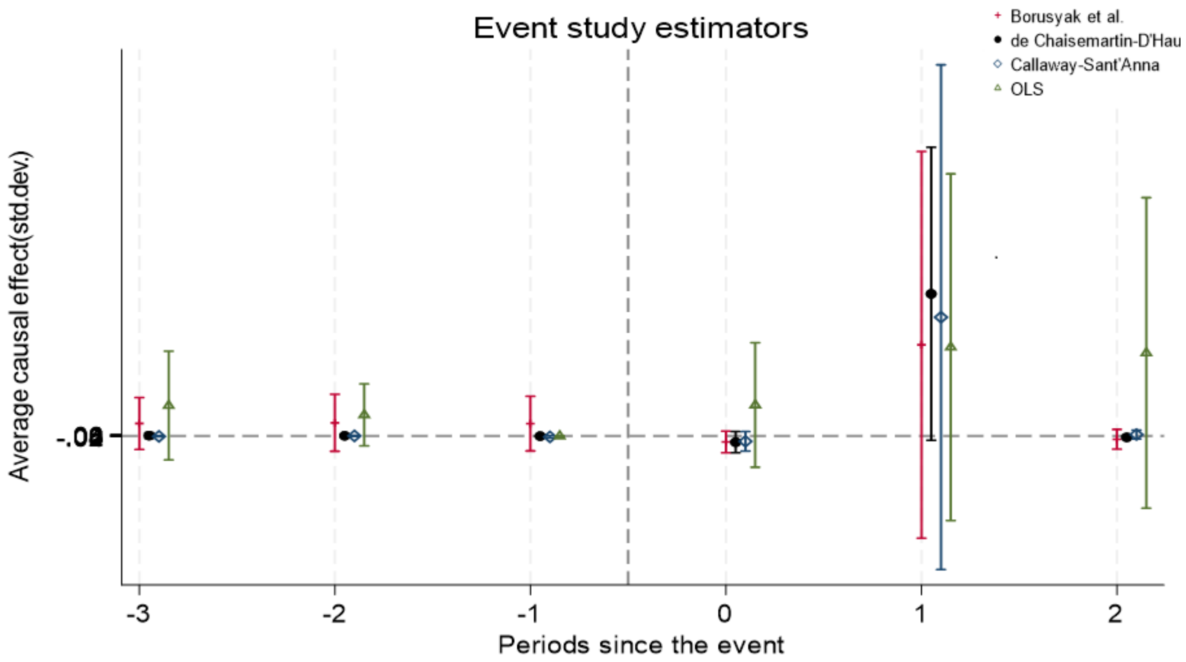


Figure 6.4.10 presents the dynamic treatment effects of broadband rollout on the ratio of service to goods revenue. The pre-treatment coefficients across all estimators are close to zero and insignificant, lending support to the parallel trends assumption. In the post-treatment periods, most estimators continue to yield coefficients is around zero with wide confidence intervals, indicating a lack of strong dynamic effects.

Figure 6.4.11 Event study effects of ADSL Broadband on service revenue

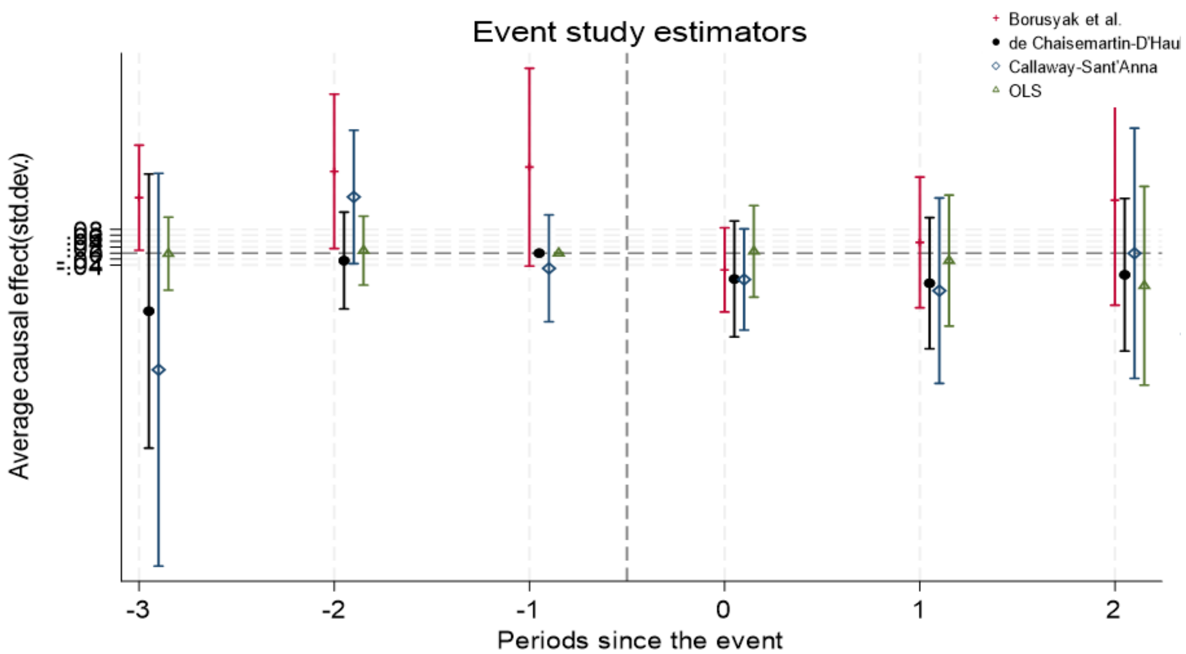


Figure 6.4.11 shows the dynamic effects of broadband rollout on the log of service

revenue. The pre-treatment estimates display considerable uncertainty, with large confidence intervals and point estimates fluctuating around zero. While none of the lead coefficients are statistically significant at 95% levels, the variation across estimators and the wide error bands suggest limited precision in identifying clear pre-trends. Nevertheless, there is no consistent upward or downward trend, which provides cautious support for the parallel trends assumption, albeit with lower statistical power than in previous specifications.

In the post-treatment period, estimated coefficients remain close to zero and insignificant across all estimators. These results suggest that broadband rollout had no significant impact on firms' total service revenue in the short run. This finding contrasts with prior results on the service-to-goods ratio, where a positive effect was observed in PPML specification.

Figure 6.4.12 Event study effects of ADSL Broadband on Ratio of service/total revenue

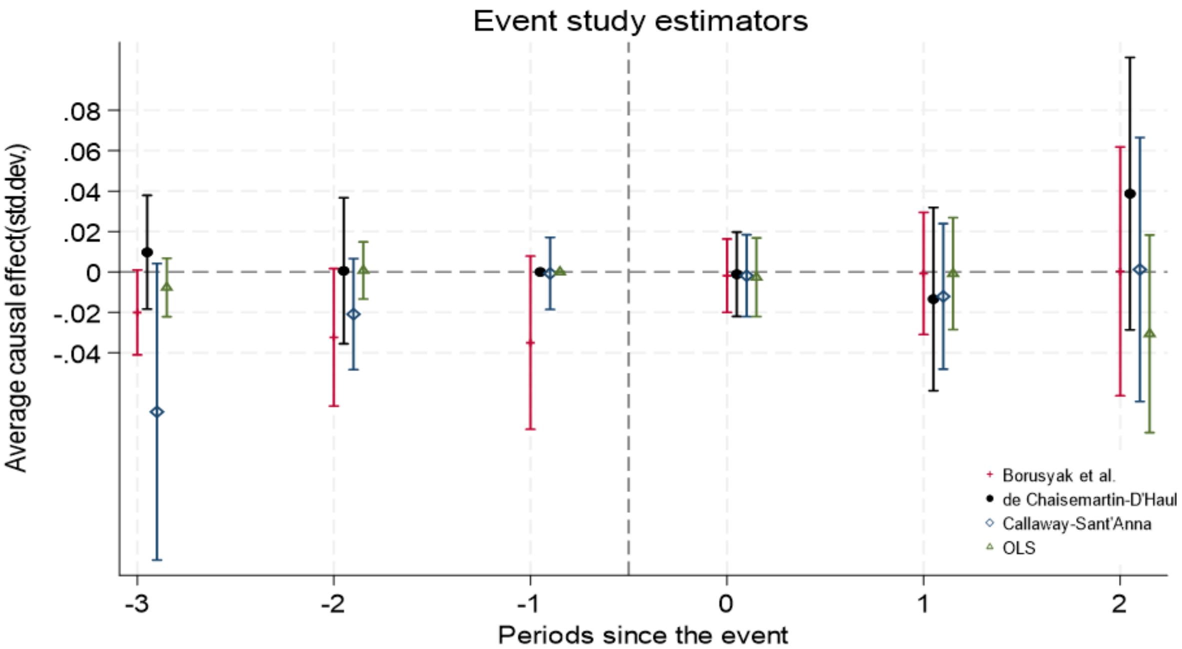


Figure 6.4.12 presents the dynamic effects of broadband rollout on the log of goods revenue, using four event study estimators. The pre-treatment coefficients are generally close to zero across estimators, with no significant differences. This lends support to the parallel trends assumption. In the post-treatment period, point estimates remain near zero. These results suggest that broadband access did not significantly impact the scale of goods production or sales in the short term.

Summing up

Overall, while the DiD design and event-study framework offers the advantage of exploiting quasi-exogenous variation in treatment timing, the lack of consistently significant results on service-related outcomes may reflect either limited policy penetration among manufacturing firms, or that the servitisation effects of broadband require longer time horizons to fully materialize. As discussed in the PPML section, our dependent variables, particularly service revenue and related ratios, exhibit a large mass at zero, which may undermine the efficiency and reliability of linear DiD estimators. These data features introduce potential bias and imprecision in the estimation of treatment effects, especially when conventional models fail to account for the non-normal and zero-inflated nature of the outcomes.

To address these concerns, our further analysis shifts to a heterogeneity framework using PPML estimation, which is better suited to the structure of our data. In particular, we examine how the effects of broadband access vary across firms with different pre-existing characteristics, including firm size, R&D intensity, service orientation, capital intensity, and skill level. By doing so, we aim to uncover the underlying channels through which broadband infrastructure may facilitate servitisation and identify which types of firms are most likely to adapt successfully in the face of digital transformation.

6.4.3 Heterogeneity Analysis

In our heterogeneity analysis, we explore how key firm-level characteristics condition the relationship between local broadband access and firms' transition toward greater service provision. To do so, we interact the local broadband access index with a range of pre-determined firm attributes that may influence a firm's capacity to benefit from digital infrastructure.

We begin by examining firm size, categorizing firms into three groups based on their initial employment level: small firms (fewer than 50 employees), medium-sized firms (50–250 employees), and large firms (more than 250 employees).

We then consider several additional firm-level dimensions that may shape servitisation dynamics: firm intensity in research and development(R&D), firm services intensity, firm intensity in capital, and the firm intensity in skilled employee. To do this we proxy the average skill level of the firm with the average firm wage in the first year we observe a firm in our data. We also use average firm services revenue in the first year we observe a firm as our initial firm services intensity. We also exploit data on the firm's initial period capital stock and the firm's initial R&D stock in order to proxy for capital intensity and firm R&D, respectively. We also include firm-level fixed effect, district-level fixed effect and year-fixed effect. Finally, we add these terms interact with local broadband access.

The model specifications are as follows:

$$\frac{SR_{ijt}}{GR_{ijt}} = \exp\left[\beta_0 + \beta_1 Z_{jt} + \beta_2 Z_{jt} \times V_{ij} + \sigma_1 \mathrm{X_{jt}} + \sigma_2 \mathrm{X_{jt}}\, \alpha_i + LA_j + Year_t + \mathrm{SIC2_{ijt}}\right] + \epsilon_{ijt} \quad (6.5)$$

V_{ij} represent initial firm size; firm initial Research and development expenditure; initial period capital stock; the initial average firm wage. We particularly interested in the interaction term coefficient β_2. X_{ijt} represent the firm level control variables, like firm age; firm foreign ownership; whether firms have multi-plant, the cost of wage; labour productivity and the cost of telecommunication. $\mathrm{X_{jt}}$ represent local economic gdp per captia.

Firm size results

To further explore whether the impact of broadband access varies by firm size, we estimate interaction models including terms for small and large firms. The specification includes a main effect for broadband access and interaction terms for Small × broadband and Large × broadband, where small firms are defined as those with ≤50 employees and large firms as those with >250 employees. The reference group is medium-sized firms.

As shown in Table 6.4.13, the coefficient on the main effect of broadband access index, which captures the impact for medium-sized firms (the reference group), is positive and significant for both the service-to-goods revenue ratio and log goods revenue. These results suggest that broadband expansion is associated with improved revenue outcomes for medium-sized firms, particularly in relation to their goods output. Turning to the interaction terms, the coefficient on Small × broadband access index is negative and significant for the service-to-goods ratio, indicating that small firms may experience a relative decline in service intensity in response to broadband access, even though the level effects on service and goods revenue are insignificant. In contrast, for large firms, the interaction term is negative and significant for goods revenue, suggesting that broadband rollout is associated with a reduction in goods revenue relative to medium-sized firms. The effects on the ratio of service revenue to good outcomes for large firms is positive but insignificant.

The heterogeneity results suggest that medium-sized firms receive the benefits of broadband expansion, particularly in terms of both revenue composition (i.e., higher service-to-goods ratios) and output growth (i.e., increased goods revenue). In contrast, small firms appear less able to translate digital infrastructure into service-oriented growth, and large firms show a decline in goods revenue following broadband rollout.

Our empirical results suggest that broadband access promotes servitisation not primarily through an increase in service revenues, but rather through structural rebalancing between goods and services. While service revenue remains relatively unchanged, the service-to-goods revenue ratio rises significantly for medium-sized firms, indicating a relative expansion of services or a reallocation of effort and revenue away from tangible outputs.

Table 6.4.13 Interaction Regressions and Beginning-of-Period Firm-Size

	(1)	(2)	(3)	(4)
	Ratio of service/total revenue	Ratio of service/Goods revenue	Services revenue	Goods revenue
Broadband access index	0.0929	1.739**	0.0523	0.0752**
	(0.132)	(0.704)	(0.155)	(0.0306)
SmallXbroadband access index	-0.0602	-1.946**	-0.233	0.0681
	(0.222)	(0.896)	(0.241)	(0.0488)
LargeXbroadband access index	-0.0598	0.639	-0.0936	-0.120***
	(0.123)	(0.816)	(0.136)	(0.0389)
Foreign	-0.0113	-0.467*	0.0454	0.0113
	(0.0484)	(0.260)	(0.0662)	(0.0208)
Age	-0.00426	0.0101	0.00230	0.00481***
	(0.0104)	(0.0544)	(0.0116)	(0.00177)
Multi-plant	0.119	0.349	-0.344*	0.0638**
	(0.128)	(0.470)	(0.206)	(0.0312)
Lntele	0.180***	0.383***	0.153***	0.116***
	(0.0501)	(0.138)	(0.0508)	(0.0242)
Lngdper	1.046*	-9.423***	0.948	-0.0113
	(0.629)	(2.892)	(0.664)	(0.219)
Lnwage	-0.0193	2.075**	0.0347	-0.0373
	(0.0912)	(0.875)	(0.149)	(0.0290)
Lnlabour	0.0652	-0.861*	0.104	0.179***
	(0.0512)	(0.447)	(0.0670)	(0.0175)
Constant	1.888	-26.28***	13.11***	10.24***
	(2.463)	(8.973)	(2.610)	(0.890)
Observations	21,709	21,470	22,151	34,909
FirmFE	YES	YES	YES	YES
YearFE				
DistrictFE	YES	YES	YES	YES
District_number	374	374	375	376
YearFEXSIC2FE	YES	YES	YES	YES
SIC2FE				

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Further Heterogeneity results

Table 6.4.14Interaction Regressions and Beginning-of-Period Firm-Level Covariates

	(1)	(2)	(3)	(4)
	Ratio of service/ goods revenue			
Broadband access index	9.312***	2.047	1.411**	-0.972
	(2.988)	(1.315)	(0.711)	(8.480)
Foreign	-0.371	-0.704	-0.727	-0.628
	(0.812)	(0.438)	(0.518)	(0.407)
Age	-0.0401	0.0738	0.0761	0.0518
	(0.0925)	(0.130)	(0.155)	(0.128)
Multi-plant	2.241***	1.112	0.818	0.803
	(0.598)	(0.830)	(0.823)	(0.803)
Lntele	0.407*	0.449*	0.489	0.499*
	(0.209)	(0.255)	(0.323)	(0.282)
Lngdper	-53.51***	-22.85***	-27.22***	-25.02***
	(8.416)	(7.038)	(7.085)	(6.407)
Lnwage	-1.793***	0.769	0.742	0.931
	(0.648)	(0.794)	(0.794)	(0.701)
Lnlabour_mp	-0.116	-0.298	-0.310	-0.291
	(0.378)	(0.338)	(0.359)	(0.329)
Broadband access index	1.404***			
	(0.514)			
Broadband access index		1.522		
		(1.857)		
Broadband access index			0.190	
			(0.314)	
Broadband access index				0.797
				(2.779)
Constant	-212.8***	-61.80***	-72.52***	-67.54***
	(34.92)	(18.83)	(19.48)	(17.90)
Observations	3,968	20,889	13,935	20,923

Notes: PPML regressions. FE indicates fixed effects in the model. Sector Time trends are two-digit UK SIC industry time trends. Standard errors are clustered at the district level and are in parentheses. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

We use firm initial RD expenditure, firm initial capital, initial services revenue and initial wage in our analysis. Table 6.4.14 shows the results of interaction regression with covariates. Column (1) shows that the interaction of broadband access index and initial R& D expenditure is positive and significant at a 1 % level. It implies that as local broadband becomes more prevalent, a firms with higher initial R&D inventories will see a stronger shift towards the service provision relative to their goods revenues. There is evidence that the knowledge intensity of firms, represented by R&D, plays a significant role in the shift towards increased service provision during the widespread adoption of broadband infrastructure. As we mentioned in the previous section, the sample here is much smaller than our baseline regression because BRED, which provides R&D variables, does not have enough observations. However, we find that initial capital stock, initial services output and the initial wage have no impact on the transition towards the service provision.

6.5 Discussion

This chapter investigates how firms adapt to the shock of broadband expansion by shifting their revenue structures toward services. In the earlier chapters, we found evidence of decline in the manufacturing sector: Chapter 4 documented falling numbers of manufacturing firms due to reduced entry and increased exit, while Chapter 5 showed that turnover and employment in manufacturing also tended to decrease (although not significant). Against this backdrop of sectoral decline, this chapter explores how surviving manufacturing firms internally respond to the new technological environment.

Our baseline regressions provide limited evidence of a direct impact, but the patterns become clearer once we adopt a more suitable estimation technique. The PPML results reveal significant and robust effects, showing that broadband access induces a reallocation of revenue composition from goods to services rather than a simple expansion of output.

To further unpack this mechanism, we explore heterogeneity across firms. The analysis demonstrates that this transformation is not uniform: firms with higher initial R&D capacity exhibit stronger shifts toward servitisation, while other factors such as capital intensity and skill level play more modest or inconsistent roles. Moreover, firm size matters. Medium-sized firms appear to be the most active drivers of servitisation, likely because they combine sufficient resources and strong motivation to experiment with digital adoption while avoiding the inertia often faced by large incumbents.

Taken together, the results tell a consistent story: broadband does not universally transform manufacturing firms, but instead provides an enabling infrastructure that allows capable and strategically positioned firms to reorient their business models toward services. Servitisation thus emerges as a selective adaptation pathway, contingent on firms' absorptive capacities and organizational characteristics, rather than an automatic outcome of digital connectivity.

From a policy perspective, these findings imply that broadband expansion alone is insufficient to revitalize the manufacturing sector. Instead, complementary policies are needed to strengthen firms' internal capabilities, such as support for R&D, digital skills training, and incentives for organizational upgrading, so that a wider range of firms can effectively leverage broadband connectivity. Without such measures, broadband risks exacerbating industrial decline by benefiting only a subset of firms that are already well-positioned to adapt.

While this chapter provides new evidence on how broadband access facilitates servitisation in manufacturing firms, several limitations also point to avenues for further research. Our data lack direct measures of firms' digital capabilities, including IT investment, adoption of broadband-based applications, and employees' digital skills. Incorporating such measures in future research would make it possible to disentangle the role of broadband infrastructure from that of actual technology usage. This extension would deepen our understanding of the mechanisms through which broadband connectivity contributes to firm-level transformation and long-term industrial change.

Chapter 7 Conclusion

This thesis investigates the economic impact of broadband infrastructure on firm behaviour in the UK, focusing on three critical dimensions: firm dynamics (entry and exit), firm performance, and the structural transformation towards servitisation in manufacturing. It also examines the role of the UK's early ADSL broadband rollout in facilitating firm development and contributing to broader economic transformation during the digital transition period.

Our contribution as follow. First, we innovatively construct a district-level broadband access index based on the Ofcom and BT broadband rollout policy data. This index provides a novel and practical proxy for measuring broadband availability at a district level in the UK, where no official firm level broadband adoption data exists. Although the index is not fully exogenous, we demonstrate that it can be credibly used in empirical research when controlling for initial local GDP conditions. Importantly, the index also allows us to identify the staggered timing of broadband treatment across districts, enabling the application of a difference-in-differences (DiD) framework to estimate the causal impact of broadband rollout on firm-level and regional economic outcomes.

The first empirical chapter (Chapter 4) examines the impact of broadband availability on firm entry and exit at the district level. To the best of our knowledge, this is the first empirical study in the UK that investigates the relationship between broadband rollout and firm dynamics, focusing on both entry and exit. The analysis is based on a novel combination of our district-level broadband index and the VAT registration dataset, which records the counts of firm registrations and de-registrations at both the district and sector-district levels. This data captures a set of small and medium-sized enterprises, offering a more comprehensive picture of firm dynamics in the UK. However, one limitation is that the data does not track individual firm-level entry and exit decisions, so the analysis remains at the aggregate district level.

Our empirical findings are particularly surprising and diverge from prior international evidence. Unlike studies that document broadband-induced increases in firm entry and/or reductions in exit, our results suggest a negative net effect of broadband rollout on firm dynamics in the UK. Specifically, a unit increase in our broadband index is associated with a 5.4% decrease in the firm entry rate(insignificant) and a 5.3% significant increase in the firm exit rate. Within a difference-in-differences framework, we further examine the causal effect, and the event study results indicate that two years after broadband rollout, the number of firm entries decreases by 5.4% and the number of firm exits increases by 5%.

We further extend the analysis to examine sectoral heterogeneity in the effects of broadband on firm dynamics. In manufacturing, broadband decrease the firm entry and increase the firm exits. In the education, broadband significantly reduces firm exit rates without affecting entry rates or the net number of firms, suggesting an improvement in firm survival. In finance, broadband has no discernible effect on entry or exit, but it significantly increases the stock of firms, a pattern consistent with scale effects rather than firm turnover. In public services, broadband simultaneously increases firm entry and the total stock of firms while leaving exit rates unaffected, indicating rapid sectoral expansion. In transportation, the primary effect of broadband is an increase in firm entry, whereas in wholesale trade, broadband raises entry rates and reduces exit rates, though without altering the overall stock of firms, implying greater churn in market participants. Taken together, these results reveal a marked contrast: manufacturing sectors experience negative impacts from broadband access, while service industries generally exhibit positive outcomes.

Chapter 5 further investigates the impact of broadband infrastructure on firm performance, following the observed negative effects on firm entry and positive effects on firm exit in Chapter 4. Using the ARDx dataset to measure our firm performance, the empirical results offer a more nuanced perspective. On average, broadband rollout has no significant effect on turnover or labour productivity. While the benchmark results suggest weak employment gains, the dynamic and heterogeneity analyses reveal that these are predominantly driven by small firms, whereas large firms actually reduce employment while improving productivity. This offsetting pattern explains why the average effects remain insignificant.

To further understand the insignificant average effects of broadband access on firm performance, we conducted a series of heterogeneity analyses along three key dimensions: firm size, industry, and urban-rural location. These results offer important explanations for the muted average effects and help uncover the underlying mechanisms.

In terms of firm size, we find that broadband has a weakly significant negative effect on turnover for medium-sized firms (-0.039), whereas small (+0.069) and large firms (+0.059) both experience positive effects. In terms of employment, small firms (+0.178) tend to expand their workforce following broadband rollout, while large firms (-0.0838) show a decline in employment. And we observe a divergence in labour productivity: while small firms (-0.106) suffer a decline in productivity, large firms (+0.14) experience gains. These opposing effects suggest that broadband adoption may disproportionately benefit larger firms, which are better equipped to absorb and utilize the new technology. In contrast, small firms may expand without corresponding productivity gains, leaving them vulnerable in an increasingly competitive environment. This mechanism potentially explains the rise in firm exits observed in Chapter 4, where smaller firms fail to survive in a market increasingly dominated by more productive, broadband-enabled large firms.

Sectoral heterogeneity also reveals distinct patterns. For instance, broadband access leads to increased employment in service sectors such as retail and catering, but reduces employment in real estate. Additionally, the motor trade sector experiences a rise in labour productivity, potentially due to improved logistics and information flow enabled by broadband infrastructure. These results suggest the importance of sector-specific characteristics in mediating broadband's effects, particularly the degree to which operations depend on information processing and digital coordination.

The urban rural analysis find weak significant positive effects on turnover and productivity are observed in rural areas. Although these effects are weak significant, it still suggests that broadband access could help the rural area firm developments.

These heterogeneity results examine the one of the key findings of our study: the effect of broadband is highly uneven. It depends on firms' capabilities to absorb the technology. Larger firms are better positioned to exploit broadband infrastructure to enhance productivity and gain competitive advantage, whereas smaller firms may be left behind. This asymmetry contributes to explain the higher exit rates observed in Chapter 4. This asymmetry in adjustment mechanisms suggests that broadband rollout acts as a catalyst for market selection: smaller firms face greater risk of exit, whereas larger, digitally capable firms consolidate their advantage.

Chapter Six explores whether broadband availability has an impact on the servitisation of manufacturing firms in the UK. Again, this is the novel empirical study to explore the broadband infrastructure effect on firm servitisation. Our results indicate that the development of broadband contributes to an increase in the proportion of service revenue within manufacturing firms, particularly the ratio of service revenue to goods revenue. However, we did not find strong evidence that broadband directly promotes the growth of service revenue. When considering the companies' R&D levels, we found that manufacturing firms with higher R&D capabilities are better positioned to leverage the benefits of broadband development, thereby increasing the proportion of service revenue to goods revenue. These results underscore the role of broadband not only in improving firm performance, but also in facilitating business model innovation and structural change.

From a policy perspective, our empirical findings reveal that broadband rollout generates not only benefits but also uneven impacts across firms and industries, challenging the common assumption that digital infrastructure universally promotes firm performance. While our analysis focuses on the early stage of ADSL broadband deployment in the UK, the policy implications should be re-evaluated in the context of 5G or AI period. However, the patterns we identify, namely high entry barriers, strong technological concentration, and asymmetric capacity to exploit new technologies, are equally relevant to the ongoing development of AI infrastructure.

First, our results show that small firms, while expanding in scale after broadband access, experience a decline in labour productivity. This weakens their competitiveness and increases their likelihood of exit. To address this, governments should provide targeted subsidies to support small and micro firms in building digital capabilities and upgrading workforce IT skills.

And digital infrastructure disproportionately strengthens large firms while crowding out smaller competitors, potentially accelerating market concentration. Regulators should closely monitor the interaction between broadband development and market concentration, ensuring that infrastructure expansion does not unintentionally reinforce monopolistic structures. In this aspect, our results provide empirical support for the rationale behind the EU Digital Markets Act, which seeks to protect the growth potential of emerging domestic technology firms.

Third, given the significant variation in broadband's effects across sectors, industrial policies should adopt a differentiated approach. For sectors with high information dependency, policy should prioritise complementary digital infrastructure investment. For sectors with weaker information dependence (e.g., traditional real estate), broadband development should be coupled with broader digital reforms, such as promoting online transaction platforms and smart rental services.

Finally, our findings on manufacturing servitisation indicate that broadband can facilitate the development of value-added services, enabling manufacturing firms to differentiate their products and enhance their competitiveness in global markets. Policymakers should integrate broadband expansion into industrial upgrading strategies to help raise the share of high-value-added segments in the UK's position within global value chains.

And several limitations of this study should be acknowledged. First, although the broadband access index we construct is considerably more exogenous than conventional measures such as regional penetration rates based on household surveys, it cannot be entirely insulated from the influence of local economic conditions. This residual endogeneity may introduce some estimation bias into our results. Second, to ensure the plausibility of policy exogeneity, our analysis focuses on a relatively short five-year window, which constrains our ability to examine the long term impacts of broadband expansion. Given that broadband effects are unlikely to materialise instantaneously; our short-term estimates may diverge from the results of studies adopting a longer-term perspective. As indicated by our DiD estimates, positive broadband effects often require time to fully emerge. Third, while our use of a difference-in-differences design and the regional GDP controls help to mitigate endogeneity concerns, these strategies cannot completely eliminate the risk. A promising avenue for further robustness checks would be to employ a credible instrumental variable for broadband access, thereby strengthening the causal interpretation of the results.

Future research could examine whether observed changes in firm entry and exit are driven by shifts in industry concentration and competitive structure. The current dataset does not permit tracking the entry and exit decisions of individual firms, which constrains the depth of our analysis on exit behaviour. This limitation could be addressed by linking our dataset with other longitudinal firm-level sources that capture firm dynamics over time. Moreover, the absence of detailed information on firms' digital capabilities, such as internal IT investments, employees' IT skills, or the actual utilisation of broadband-enabled applications, prevents us from empirically disentangling the role of broadband infrastructure from that of broadband capital utilisation within firms. With access to such data, future research could explicitly separate these two channels, providing a clearer understanding of the mechanisms through which broadband affects firm performance and competitive outcomes.

Reference

Acemoglu, D., Aghion, P., Lelarge, C., Van Reenen, J., & Zilibotti, F. (2007). Technology, Information, and the Decentralization of the Firm. *The Quarterly Journal of Economics*, *122*(4), 1759-1799.

Acemoglu, D., Autor, D., Dorn, D., Hanson, G. H., & Price, B. (2014). Return of the Solow paradox? IT, productivity, and employment in US manufacturing. *American Economic Review*, *104*(5), 394-399.

Ahlfeldt, G., Koutroumpis, P., & Valletti, T. (2017). Speed 2.0: Evaluating access to universal digital highways. *Journal of the European Economic Association*, *15*(3), 586-625.

Akerman, A., Gaarder, I., & Mogstad, M. (2015). The skill complementarity of broadband Internet. *The Quarterly Journal of Economics*, *130*(4), 1781-1824.

Akerman, A., Leuven, E., & Mogstad, M. (2022). Information frictions, Internet, and the relationship between distance and trade. *American Economic Journal: Applied Economics*, *14*(1), 133-163.

Allen, T. (2014). Information frictions in trade. *Econometrica*, *82*(6), 2041-2083.

Amaral-Garcia, S., Nardotto, M., Propper, C., & Valletti, T. (2022). Mums go online: Is the Internet changing the demand for health care?. *Review of Economics and Statistics*, *104*(6), 1157-1173.

Appiah-Otoo, I., & Song, N. (2021). The impact of ICT on economic growth-Comparing rich and poor countries. *Telecommunications Policy*, *45*(2), 102082.

Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G., & Ruggeri, C. (2018). The role of digital technologies for the service transformation of industrial companies. *International journal of production research*, *56*(6), 2116-2132.

Atasoy, H. (2013). The effects of broadband Internet expansion on labour market outcomes. *ILR review*, *66*(2), 315-345.

Audretsch, D. B., Heger, D., & Veith, T. (2015). Infrastructure and entrepreneurship. *Small Business Economics*, *44*, 219-230.

Autor, D. H. (2001). Wiring the labour market. *Journal of Economic Perspectives*, *15*(1), 25-40.

Bai, Y. (2017). The faster, the better? The impact of Internet speed on employment. *Information Economics and Policy*, *40*, 21-25.

Baines, T. S., Lightfoot, H. W., Benedettini, O., & Kay, J. M. (2009). The servitisation of manufacturing: A review of literature and reflection on future challenges. *Journal of manufacturing technology management*, *20*(5), 547-567.

Bakos, J. Y. (1997). Reducing buyer search costs: Implications for electronic marketplaces. *Management science*, *43*(12), 1676-1692.

Bakos, Y. (2001). The emerging landscape for retail e-commerce. *Journal of economic perspectives*, *15*(1), 69-80.

Bar-Isaac, H., Caruana, G., & Cuñat, V. (2012). Search, design, and market structure. *American Economic Review*, *102*(2), 1140-1160.

Bartel, A., Ichniowski, C., & Shaw, K. (2007). How does information technology affect productivity? Plant-level comparisons of product innovation, process improvement, and worker skills. *The quarterly journal of Economics*, *122*(4), 1721-1758.

Beck, T., Levine, R., & Levkov, A. (2010). Big bad banks? The winners and losers from bank deregulation in the United States. *The journal of finance*, *65*(5), 1637-1667.

Bergeaud, A., Malgouyres, C., Mazet-Sonilhac, C., & Signorelli, S. (2021). Technological change and domestic outsourcing.

Bertschek, I., Cerquera, D., & Klein, G. J. (2013). More bits–more bucks? Measuring the impact of broadband Internet on firm performance. *Information Economics and Policy*, *25*(3), 190-203.

Bertschek, I., Hogrefe, J., & Rasel, F. (2015). Trade and technology: new evidence on the productivity sorting of firms. *Review of World Economics*, *151*, 53-72.

Bessone, P., Campante, F. R., Ferraz, C., & Souza, P. (2022). *Social media and the behaviour of politicians: Evidence from Facebook in Brazil* (No. w30306). National Bureau of Economic Research.

Bhuller, M., Ferraro, D., Kostøl, A. R., & Vigtel, T. C. (2023). *The Internet, search frictions and aggregate unemployment* (No. w30911). National Bureau of Economic Research.

Billari, F. C., Giuntella, O., & Stella, L. (2018). Broadband Internet, digital temptations, and sleep. *Journal of Economic Behaviour & Organization*, *153*, 58-76.

Blank, G., Graham, M., & Calvino, C. (2018). Local geographies of digital inequality. *Social Science Computer Review*, *36*(1), 82-102.

Bloom, N., Garicano, L., Sadun, R., & Van Reenen, J. (2014). The distinct effects of information technology and communication technology on firm organization. *Management Science*, *60*(12), 2859-2885.

Bloom, N., Sadun, R., & Reenen, J. V. (2012). Americans do IT better: US multinationals and the productivity miracle. *American Economic Review*, *102*(1), 167-201.

Borenstein, S., & Saloner, G. (2001). Economics and electronic commerce. *Journal of Economic Perspectives*, *15*(1), 3-12.

Borusyak, K., Jaravel, X., & Spiess, J. (2024). Revisiting event-study designs: robust and efficient estimation. *Review of Economic Studies*, rdae007.

Braghieri, L., Levy, R. E., & Makarin, A. (2022). Social media and mental health. *American Economic Review*, *112*(11), 3660-3693.

Brax, S. (2005). A manufacturer becoming service provider–challenges and a paradox. *Managing Service Quality: An International Journal*, *15*(2), 142-155.

Breinlich, H., Soderbery, A., & Wright, G. C. (2018). From selling goods to selling services: Firm responses to trade liberalization. *American Economic Journal: Economic Policy*, *10*(4), 79-108.

Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies 'Engines of growth'?. *Journal of econometrics*, *65*(1), 83-108.

Briggs, L. (2000, December 20). E-commerce 2000: The year of living dangerously. *E-Commerce Times*. **https://www.ecommercetimes.com/story/e-commerce-2000-the-year-of-living-dangerously-6380.html**

Brynjolfsson, E., Hu, Y., & Rahman, M. S. (2009). Battle of the retail channels: How product selection and geography drive cross-channel competition. *Management Science*, *55*(11), 1755-1765.

Callaway, B., & Sant'Anna, P. H. (2021). Difference-in-differences with multiple time periods. *Journal of econometrics*, *225*(2), 200-230.

Calle, A. D. L., Freije, I., Ugarte, J. V., & Larrinaga, M. Á. (2020). Measuring the impact of digital capabilities on product-service innovation in Spanish industries. *International Journal of Business Environment*, *11*(3), 254-274.

Cambini, C., & Sabatino, L. (2023). Digital highways and firm turnover. *Journal of economics & management strategy*, *32*(4), 673-713.

Cambini, C., Sabatino, L., & Zaccagni, S. (2021). The Faster the Better? The Effect of Ultra-Fast Broadband on Students' Performance. *The Effect of Ultra-Fast Broadband on Students' Performance (September 16, 2021)*.

Campante, F., Durante, R., & Sobbrio, F. (2018). Politics 2.0: The multifaceted effect of broadband Internet on political participation. *Journal of the European Economic Association*, *16*(4), 1094-1136.

Canzian, G., Poy, S., & Schüller, S. (2019). Broadband upgrade and firm performance in rural areas: Quasi-experimental evidence. *Regional Science and Urban Economics*, *77*, 87-103.

Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: conclusions from the empirical literature. *Information Economics and policy*, *25*(3), 109-125.

Cardona, Melisande, Tobias Kretschmer, and Thomas Strobel. "ICT and productivity: conclusions from the empirical literature." *Information Economics and policy* 25.3 (2013): 109-125.

Celbis, M. G., & de Crombrugghe, D. (2018). Internet infrastructure and regional convergence: Evidence from Turkey. *Papers in Regional Science*, *97*(2), 387-409.

Chen, S., & Zhang, H. (2021). Does digital finance promote manufacturing servitisation: Micro evidence from China. *International Review of Economics & Finance*, *76*, 856-869.

Chen, Y., Ma, L., & Orazem, P. F. (2023). The heterogeneous role of broadband access on establishment entry and exit by sector and urban and rural markets. Telecommunications Policy, 47(3), 102504.

Chen, Zhenhua, and Kingsley E. Haynes. "Impact of high-speed rail on regional economic disparity in China." *Journal of Transport Geography* 65 (2017): 80-91.

Choi, C., & Yi, M. H. (2009). The effect of the Internet on economic growth: Evidence from cross-country panel data. *Economics letters*, *105*(1), 39-41.

Choi, J., & Bell, D. R. (2011). Preference minorities and the Internet. *Journal of Marketing Research*, *48*(4), 670-682.

Coreynen, W., Matthyssens, P., & Van Bockhaven, W. (2017). Boosting servitisation through digitization: Pathways and dynamic resource configurations for manufacturers. *Industrial marketing management*, *60*, 42-53.

Cramer, J., & Krueger, A. B. (2016). Disruptive change in the taxi business: The case of Uber. American Economic Review, 106(5), 177-182.

Crandall, R. W., Lehr, W., & Litan, R. E. (2007). *The effects of broadband deployment on output and employment: A cross-sectional analysis of US data* (Vol. 6). Washington, DC: Brookings Institution.

Crozet, M., & Milet, E. (2017). Should everybody be in services? The effect of servitisation on manufacturing firm performance. *Journal of Economics & Management Strategy*, *26*(4), 820-841.

Cumming, D., & Johan, S. (2010). The differential impact of the Internet on spurring regional entrepreneurship. *Entrepreneurship Theory and Practice*, *34*(5), 857-884.

Czernich, N. (2012). Broadband Internet and political participation: Evidence for g ermany. *Kyklos*, *65*(1), 31-52.

Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal*, *121*(552), 505-532.

D'Andrea, A., & Limodio, N. (2024). High-speed Internet, financial technology, and banking. *Management Science*, *70*(2), 773-798.

De Chaisemartin, C., & d'Haultfoeuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American economic review*, *110*(9), 2964-2996.

Dean, D., DiGrande, S., Field, D., Lundmark, A., O'day, J., Pineda, J., & Zwillenberg, P. (2012). The Internet economy in the G-20. *The Boston*.

Dedrick, J., Kraemer, K. L., & Shih, E. (2013). Information technology and productivity in developed and developing countries. *Journal of Management Information Systems*, *30*(1), 97-122.

Department for Business and Trade. (2023). *Business population estimates for the UK and regions: 2023 statistical release*. UK Government. **https://www.gov.uk/government/statistics/business-population-estimates-2023/business-population-estimates-for-the-uk-and-regions-2023-statistical-release**

Department for Digital, Culture, Media and Sport. (2021). *Superfast Broadband Programme – Synthesis Report.* UK Government. https://assets.publishing.service.gov.uk/media/61571a468fa8f52982a85fcf/Superfast_Broadband_evaluation_sythesis_report.pdf

DeStefano, T., Kneller, R., & Timmis, J. (2018). Broadband infrastructure, ICT use and firm performance: Evidence for UK firms. *Journal of Economic Behaviour & Organization*, *155*, 110-139.

DeStefano, T., Kneller, R., & Timmis, J. (2023). The (fuzzy) digital divide: the effect of universal broadband on firm performance. *Journal of Economic Geography*, *23*(1), 139-177.

Dewan, S., & Kraemer, K. L. (2000). Information technology and productivity: Evidence from country-level data. *Management science*, *46*(4), 548-562.

Dingel, J. I. (2020). How Many Jobs Can be Done at Home?.

Dinterman, R., & Renkow, M. (2017). Evaluation of USDA's Broadband Loan Program: Impacts on broadband provision. *Telecommunications Policy*, *41*(2), 140-153.

Dodlova, M., Kis-Katos, K., Kochanova, A., & Wirth, O. (2023). Mobile technologies and firm formalization.

Donati, D. (2023). Mobile Internet access and political outcomes: Evidence from South Africa. *Journal of Development Economics*, *162*, 103073.

Donati, D., Durante, R., Sobbrio, F., & Zejcirovic, D. (2022). Lost in the net? broadband Internet and youth mental health. *Broadband Internet and Youth Mental Health (April 2022)*.

Duvivier, C. (2019). Broadband and Firm Location: Some answers to relevant policy and research issues using meta-analysis. *Canadian Journal of Regional Science*, *42*(1), 24-45.

Duvivier, C., & Bussière, C. (2022). The contingent nature of broadband as an engine for business startups in rural areas. *Journal of Regional Science*, *62*(5), 1329-1357.

Edquist, H., & Henrekson, M. (2017). Swedish lessons: How important are ICT and R&D to economic growth?. *Structural Change and Economic Dynamics*, *42*, 1-12.

Eggert, A., Hogreve, J., Ulaga, W., & Muenkhoff, E. (2014). Revenue and profit implications of industrial service strategies. *Journal of Service Research*, *17*(1), 23-39.

Faber, B., Sanchis-Guarner, R., & Weinhardt, F. (2015). *ICT and education: Evidence from student home addresses* (No. w21306). National Bureau of Economic Research.

Fabritz, N. (2013). *The impact of broadband on economic activity in rural areas: evidence from German municipalities* (No. 166). Ifo Working Paper.

Fairlie, R. W. (2006). The personal computer and entrepreneurship. *Management Science*, *52*(2), 187-203.

Falck, O., Gold, R., & Heblich, S. (2014). E-lections: Voting Behaviour and the Internet. *American Economic Review*, *104*(7), 2238-2265.

Fan, J., Tang, L., Zhu, W., & Zou, B. (2018). The Alibaba effect: Spatial consumption inequality and the welfare gains from e-commerce. *Journal of International Economics*, *114*, 203-220.

Fang, E., Palmatier, R. W., & Steenkamp, J. B. E. (2008). Effect of service transition strategies on firm value. *Journal of marketing*, *72*(5), 1-14.

Favoretto, C., Mendes, G. H., Oliveira, M. G., Cauchick-Miguel, P. A., & Coreynen, W. (2022). From servitisation to digital servitisation: How digitalisation transforms companies' transition towards services. *Industrial marketing management*, *102*, 104-121.

Ford, G. S. (2018). Is faster better? Quantifying the relationship between broadband speed and economic growth. *Telecommunications Policy*, *42*(9), 766-777.

Forman, C., & McElheran, K. (2013). The digital reorganization of firm boundaries: IT use and vertical integration in US manufacturing. *Georgia Institute of Technology Working Paper*.

Forman, C., & Zeebroeck, N. V. (2012). From wires to partners: How the Internet has fostered R&D collabourations within firms. *Management science*, *58*(8), 1549-1568.

Forman, C., Ghose, A., & Goldfarb, A. (2009). Competition between local and electronic markets: How the benefit of buying online depends on where you live. *Management science*, *55*(1), 47-57.

Forman, C., Goldfarb, A., & Greenstein, S. (2012). The Internet and local wages: A puzzle. *American Economic Review*, *102*(1), 556-575.

Freund, C. L., & Weinhold, D. (2004). The effect of the Internet on international trade. *Journal of international economics*, *62*(1), 171-189.

Fudenberg, D., & Villas-Boas, J. M. (2012). In the digital economy. *e Oxford Handbook of the Digital Economy*, *254*.

Gal, P., Nicoletti, G., Renault, T., Sorbe, S., & Timiliotis, C. (2019). Digitalisation and productivity: In search of the holy grail–Firm-level empirical evidence from EU countries.

Garicano, L. (2010). Policemen, managers, lawyers: New results on complementarities between organization and information and communication technology. *International Journal of Industrial Organization*, *28*(4), 355-358.

Garicano, L., & Heaton, P. (2010). Information technology, organization, and productivity in the public sector: Evidence from police departments. *Journal of Labour Economics*, *28*(1), 167-201.

Gaspar, J., & Glaeser, E. L. (1998). Information technology and the future of cities. *Journal of urban economics*, *43*(1), 136-156.

Gavazza, A., Nardotto, M., & Valletti, T. (2019). Internet and politics: Evidence from UK local elections and local government policies. *The Review of Economic Studies*, *86*(5), 2092-2135.

Gebauer, H., Fleisch, E., & Friedli, T. (2005). Overcoming the service paradox in manufacturing companies. *European management journal*, *23*(1), 14-26.

Gebauer, H., Paiola, M., Saccani, N., & Rapaccini, M. (2021). Digital servitisation: Crossing the perspectives of digitization and servitisation. *Industrial Marketing Management*, *93*, 382-388.

Gebauer, H., Ren, G. J., Valtakoski, A., & Reynoso, J. (2012). Service-driven manufacturing: Provision, evolution and financial impact of services in industrial firms. *Journal of Service Management*, *23*(1), 120-136.

Gebauer, Heiko, et al. "Digital servitisation: Crossing the perspectives of digitization and servitisation." *Industrial Marketing Management* 93 (2021): 382-388.

Geraci, A., Nardotto, M., Reggiani, T., & Sabatini, F. (2022). Broadband Internet and social capital. *Journal of Public Economics*, *206*, 104578.

Ghio, N., Guerini, M., Lehmann, E. E., & Rossi-Lamastra, C. (2015). The emergence of the knowledge spillover theory of entrepreneurship. *Small Business Economics*, *44*, 1-18.

Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of economic literature*, *57*(1), 3-43.

Goldfarb, A., McDevitt, R. C., Samila, S., & Silverman, B. S. (2015). The effect of social interaction on economic transactions: Evidence from changes in two retail formats. *Management Science*, *61*(12), 2963-2981.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of econometrics*, *225*(2), 254-277.

Gravity Internet. *Common Internet terms*. Gravity Internet. https://getgravity.nz/blog/common-Internet-terms/

Greenstein, S., & McDevitt, R. C. (2009). *The broadband bonus: Accounting for broadband Internet's impact on US GDP* (No. w14758). National Bureau of Economic Research.

Grimes, A., Ren, C., & Stevens, P. (2012). The need for speed: impacts of Internet connectivity on firm productivity. *Journal of Productivity Analysis*, *37*(2), 187-201.

Guriev, S., Melnikov, N., & Zhuravskaya, E. (2021). 3g Internet and confidence in government. *The Quarterly Journal of Economics*, *136*(4), 2533-2613.

Gurney, K. A. (2012). *The Local Economic Growth Impact of Broadband Infrastructure 1998 to 2008* (Doctoral dissertation, Cleveland State University).

Gurney, Karen A. *The Local Economic Growth Impact of Broadband Infrastructure 1998 to 2008*. Diss. Cleveland State University, 2012.

Gürtzgen, N., Diegmann, A., Pohlan, L., & van den Berg, G. J. (2021). Do digital information technologies help unemployed job seekers find a job? Evidence from the broadband Internet expansion in Germany. *European Economic Review*, *132*, 103657.

Hagiu, A. (2012). "Software Platforms." In The Oxford Handbook of the Digital Economy, edited by Martin Peitz and Joel Waldfogel, 59–82. Oxford and New York: Oxford University Press.

Hagiu, A. (2012). Software platforms. In M. Peitz & J. Waldfogel (Eds.), *The Oxford handbook of the digital economy* (pp. 59–82). Oxford University Press.

Haller, S. A., & Lyons, S. (2019). Effects of broadband availability on total factor productivity in service sector firms: Evidence from Ireland. *Telecommunications Policy*, *43*(1), 11-22.

Haller, S. A., & Siedschlag, I. (2011). Determinants of ICT adoption: Evidence from firm-level data. *Applied Economics*, *43*(26), 3775-3788.

Harrmann, L. K., Eggert, A., & Böhm, E. (2023). Digital technology usage as a driver of servitisation paths in manufacturing industries. *European Journal of Marketing*, *57*(3), 834-857.

Harrmann, Lisa Katharina, Andreas Eggert, and Eva Böhm. "Digital technology usage as a driver of servitisation paths in manufacturing industries." *European Journal of Marketing* 57.3 (2023): 834-857.

Hasbi, M. (2017). Impact of very high-speed broadband on local economic growth: Empirical evidence.

Hjort, J., & Poulsen, J. (2019). The arrival of fast Internet and employment in Africa. *American Economic Review*, *109*(3), 1032-1079.

Holl, A. (2016). Highways and productivity in manufacturing firms. *Journal of Urban Economics*, *93*, 131-151.

Holt, L., & Jamison, M. (2009). Broadband and contributions to economic growth: Lessons from the US experience. *Telecommunications Policy*, *33*(10-11), 575-581.

Huikkola, T., Rabetino, R., Kohtamäki, M., & Gebauer, H. (2020). Firm boundaries in servitisation: Interplay and repositioning practices. *Industrial Marketing Management*, *90*, 90-105.

Ivus, O., & Boland, M. (2015). The employment and wage impact of broadband deployment in Canada. *Canadian Journal of Economics/Revue canadienne d'économique*, *48*(5), 1803-1830.

Jayakar, K., & Park, E. A. (2013). Broadband availability and employment: An analysis of county-level data from the National Broadband Map. *Journal of Information Policy*, *3*, 181-200.

Jin, X., Ma, B., & Zhang, H. (2023). Impact of fast Internet access on employment: Evidence from a broadband expansion in China. *China Economic Review*, *81*, 102038.

Jung, J., & López-Bazo, E. (2020). On the regional impact of broadband on productivity: The case of Brazil. *Telecommunications Policy*, *44*(1), 101826.

Kandilov, I. T., & Renkow, M. (2010). Infrastructure investment and rural economic development: An evaluation of USDA's broadband loan program. *Growth and Change*, *41*(2), 165-191.

Kastalli, I. V., & Van Looy, B. (2013). Servitisation: Disentangling the impact of service business model innovation on manufacturing firm performance. *Journal of operations management*, *31*(4), 169-180.

Kim, Y., & Orazem, P. F. (2017). Broadband Internet and new firm location decisions in rural areas. *American Journal of Agricultural Economics*, *99*(1), 1-18.

Kohtamaki, M., Hakala, H., Partanen, J., Parida, V., & Wincent, J. (2015). The performance impact of industrial services and service orientation on manufacturing companies. *Journal of Service Theory and Practice*, *25*(4), 463-485.

Kohtamäki, M., Partanen, J., Parida, V., & Wincent, J. (2013). Non-linear relationship between industrial service offering and sales growth: The moderating role of network capabilities. *Industrial Marketing Management*, *42*(8), 1374-1385.

Kolko, J. (2012). Broadband and local growth. *Journal of Urban Economics*, *71*(1), 100-113.

Koutroumpis, P. (2009). The economic impact of broadband on growth: A simultaneous approach. *Telecommunications policy*, *33*(9), 471-485.

Kowalkowski, C., Gebauer, H., Kamp, B., & Parry, G. (2017). Servitisation and deservitisation: Overview, concepts, and definitions. *Industrial Marketing Management*, *60*, 4-10.

Kroft, K., & Pope, D. G. (2014). Does online search crowd out traditional search and improve matching efficiency? Evidence from Craigslist. *Journal of Labour Economics*, *32*(2), 259-303.

Kuhn, P., & Mansour, H. (2014). Is Internet job search still ineffective?. *The Economic Journal*, *124*(581), 1213-1233.

Lapointe, P. (2015). *Does speed matter? The employment impact of increasing access to fiber Internet*. Georgetown University.

Leamer, E. E. (2007). A flat world, a level playing field, a small world after all, or none of the above? A review of Thomas L. Friedman's The World is Flat. *Journal of Economic Literature*, *45*(1), 83-126.

Leamer, E. E. (2007). A flat world, a level playing field, a small world after all, or none of the above? A review of Thomas L. Friedman's The World is Flat. Journal of Economic Literature, 45(1), 83-126.

Leeflang, P. S., Verhoef, P. C., Dahlström, P., & Freundt, T. (2014). Challenges and solutions for marketing in a digital era. *European management journal*, *32*(1), 1-12.

Lehr, W. H., Osorio, C., Gillett, S. E., & Sirbu, M. A. (2006). Measuring broadband's economic impact.

Lendle, A., Olarreaga, M., Schropp, S., & Vézina, P. L. (2016). There goes gravity: eBay and the death of distance. *The Economic Journal*, *126*(591), 406-441.

Levinsohn, J., & Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *The review of economic studies*, *70*(2), 317-341.

Lieber, E., & Syverson, C. (2012). Online versus offline competition. *The Oxford handbook of the digital economy*, *189*, 1-29.

Lightfoot, H., Baines, T., & Smart, P. (2013). The servitisation of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations & Production Management*, *33*(11/12), 1408-1434.

Loginova, O. (2009). Exposure order effects and advertising competition. *Journal of Economic Behaviour & Organization*, *71*(2), 528-538.

Luca, M. (2016). Reviews, reputation, and revenue: The case of Yelp. com. *Com (March 15, 2016). Harvard Business School NOM Unit Working Paper*, (12-016).

Mack, E. A. (2014). Businesses and the need for speed: The impact of broadband speed on business presence. *Telematics and Informatics*, *31*(4), 617-627.

Mack, E. A. (2015). Variations in the broadband-business connection across the urban hierarchy. *Growth and Change*, *46*(3), 400-423.

Mack, E. A., & Grubesic, T. H. (2009). Broadband provision and firm location in Ohio: An exploratory spatial analysis. *Tijdschrift voor economische en sociale geografie*, *100*(3), 298-315.

Mack, E. A., & Rey, S. J. (2014). An econometric approach for evaluating the linkages between broadband and knowledge intensive firms. *Telecommunications Policy*, *38*(1), 105-118.

Mack, E. A., & Wentz, E. (2017). Industry variations in the broadband business nexus. *Socio-Economic Planning Sciences*, *58*, 51-62.

Malgouyres, C., Mayer, T., & Mazet-Sonilhac, C. (2021). Technology-induced trade shocks? Evidence from broadband expansion in France. *Journal of International Economics*, *133*, 103520.

Maliranta, M., & Rouvinen, P. (2006). Informational mobility and productivity: Finnish evidence. *Econ. Innov. New Techn.*, *15*(6), 605-616.

Martín-Peña, M. L., Sánchez-López, J. M., & Díaz-Garrido, E. (2019). Servitisation and digitalisation in manufacturing: the influence on firm performance. *Journal of Business & Industrial Marketing*, *35*(3), 564-574.

Maurseth, P. B. (2018). The effect of the Internet on economic growth: Counter-evidence from cross-country panel data. *Economics Letters*, *172*, 74-77.

McCoy, D., Lyons, S., Morgenroth, E., Palcic, D., & Allen, L. (2018). The impact of broadband and other infrastructure on the location of new business establishments. *Journal of regional science*, *58*(3), 509-534.

McDool, E., Powell, P., Roberts, J., & Taylor, K. (2020). The Internet and Children's Psychological well-being. *Journal of health economics*, *69*, 102274.

Meier, H., Roy, R., & Seliger, G. (2010). Industrial product-service systems—IPS2. *CIRP annals*, *59*(2), 607-627.

Meijers, H. (2014). Does the Internet generate economic growth, international trade, or both?. *International Economics and Economic Policy*, *11*, 137-163.

Michaels, G., Natraj, A., & Van Reenen, J. (2014). Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years. *Review of Economics and Statistics*, *96*(1), 60-77.

Myovella, G., Karacuka, M., & Haucap, J. (2020). Digitalisation and economic growth: A comparative analysis of Sub-Saharan Africa and OECD economies. *Telecommunications Policy*, *44*(2), 101856.

Neely, A. (2008). Exploring the financial consequences of the servitisation of manufacturing. *Operations management research*, *1*, 103-118.

Neely, A., Benedettini, O., & Visnjic, I. (2011, July). The servitisation of manufacturing: Further evidence. In *18th European operations management association conference* (Vol. 1).

Nomis. *Official labour market statistics*. Office for National Statistics. Retrieved from https://www.nomisweb.co.uk/

OECD (2008), *OECD Information Technology Outlook 2008*, OECD Publishing, Paris, https://doi.org/10.1787/it_outlook-2008-en.

Ofcom.(2004). *Internet and Broadband Update January 2004.*ofcom. https://www.ofcom.org.uk/siteassets/resources/documents/research-and-data/telecoms-research/other-telecoms/Internetandbroadband.pdf?v=331965

Office for National Statistics (ONS). (2024). *Annual Respondents Database X, 1997-2020: Secure Access*. [data collection]. *5th Edition.* Office for National Statistics, [original data producer(s)]. Office for National Statistics. SN: 7989, DOI: http://doi.org/10.5255/UKDA-SN-7989-5

Office for National Statistics. (2004). *Rural-urban definition: England and Wales*. https://www.ons.gov.uk/methodology/geography/geographicalproducts/ruralurbanclassifications/2001ruralurbanclassification/ruralurbandefinitionenglandandwales

Office for National Statistics. (2023). *UK Standard Industrial Classification of Economic Activities*. https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities

Office for National Statistics. (2023). *Annual Business Survey, 2005-2021: Secure Access*. [data collection]. *17th Edition*. UK Data Service. SN: 7451, DOI: http://doi.org/10.5255/UKDA-SN-7451-17

Office for National Statistics. (2023). *Business Expenditure on Research and Development, 1995-2021: Secure Access*. [data collection]. *12th Edition*. UK Data Service. SN: 6690, DOI: http://doi.org/10.5255/UKDA-SN-6690-12

Office for National Statistics. *2001 census data*. Office for National Statistics. https://www.ons.gov.uk/census/2011census/2011censusdata/2001censusdata

Oliva, R., & Kallenberg, R. (2003). Managing the transition from products to services. *International journal of service industry management*, *14*(2), 160-172.

Percoco, M. (2016). Highways, local economic structure and urban development. *Journal of Economic Geography*, *16*(5), 1035-1054.

Pilat, D., Cimper, A., Olsen, K. B., & Webb, C. (2006). The changing nature of manufacturing in OECD economies.

Point Topic.com *Global broadband statistics*. Point Topic from https://www.point-topic.com/

Pozzi, A. (2013). E-commerce as a stockpiling technology: Implications for consumer savings. *International Journal of Industrial Organization*, *31*(6), 677-689.

Pozzi, A. (2013). The effect of Internet distribution on brick-and-mortar sales. *The RAND Journal of Economics*, *44*(3), 569-583.

Prieger, J. E., Lu, H., & Zhang, H. (2017). The importance of transportation, broadband, and intellectual infrastructure for entrepreneurship.

Raddats, C., Kowalkowski, C., Benedettini, O., Burton, J., & Gebauer, H. (2019). Servitisation: A contemporary thematic review of four major research streams. *Industrial Marketing Management*, *83*, 207-223.

Riddlesden, D., & Singleton, A. D. (2014). Broadband speed equity: A new digital divide?. *Applied Geography*, *52*, 25-33.

Rivares, A. B., Gal, P., Millot, V., & Sorbe, S. (2019). Like it or not? The impact of online platforms on the productivity of incumbent service providers.

Sabatini, F. (2023). The behavioural, economic, and political impact of the Internet and social media: Empirical challenges and approaches. *Journal of Economic Surveys*.

SamKnows. *Internet availability checker*. SamKnows. https://availability.samknows.com/

SCG Connected. (2024). *ADSL speeds and distance* [Image]. SCG Connected. https://www.scgconnected.co.uk/faq/what-adsl-speeds-and-distance-can-you-expect/

Seamans, R., & Zhu, F. (2014). Responses to entry in multi-sided markets: The impact of Craigslist on local newspapers. *Management Science*, *60*(2), 476-493.

Shideler, D., & Badasyan, N. (2012). Broadband impact on small business growth in Kentucky. *Journal of Small Business and Enterprise Development*, *19*(4), 589-606.

Small, K., & Verhoef, E. T. (2007). *The economics of urban transportation*. Routledge.

Sousa, R., & da Silveira, G. J. (2017). Capability antecedents and performance outcomes of servitisation: Differences between basic and advanced services. *International Journal of Operations & Production Management*, *37*(4), 444-467.

Suarez, F. F., Cusumano, M. A., & Kahl, S. J. (2013). Services and the business models of product firms: An empirical analysis of the software industry. *Management Science*, *59*(2), 420-435.

Sun, L., & Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of econometrics*, *225*(2), 175-199.

Syverson, C. (2011). What determines productivity?. *Journal of Economic literature*, *49*(2), 326-365.

Tabellini, G., Manacorda, M., & Tesei, A. (2023). Mobile Internet and the rise of communitarian politics. *Andrea, Mobile Internet and the Rise of Communitarian Politics (April 6, 2023)*.

Taneja, S., & Toombs, L. (2014). Putting a face on small businesses: Visibility, viability, and sustainability the impact of social media on small business marketing. *Academy of marketing studies journal*, *18*(1), 249.

Taneja, S., & Toombs, L. (2014). Putting a face on small businesses: Visibility, viability, and sustainability the impact of social media on small business marketing. Academy of marketing studies journal, 18(1), 249.

Thompson Jr, H. G., & Garbacz, C. (2011). Economic impacts of mobile versus fixed broadband. *Telecommunications Policy*, *35*(11), 999-1009.

Toader, E., Firtescu, B. N., Roman, A., & Anton, S. G. (2018). Impact of information and communication technology infrastructure on economic growth: An empirical assessment for the EU countries. *Sustainability*, *10*(10), 3750.

Tranos, E., & Mack, E. A. (2016). Broadband provision and knowledge-intensive firms: A causal relationship?. Regional Studies, 50(7), 1113-1126.

Tranos, E., Kitsos, T., & Ortega-Argilés, R. (2021). Digital economy in the UK: regional productivity effects of early adoption. *Regional Studies*, *55*(12), 1924-1938.

UCTAD. *Digital Economy Report (2019)*.UCTAD. https://unctad.org/publication/digital-economy-report-2019

Ulaga, W., & Reinartz, W. J. (2011). Hybrid offerings: How manufacturing firms combine goods and services successfully. *Journal of marketing*, *75*(6), 5-23.4

Valtakoski, A. (2011). The impact of knowledge-intensive service provision on SME performance: A study in software industry.

Van Gaasbeck, K. A. (2008). A rising tide: Measuring the economic effects of broadband use across California. *The Social Science Journal*, *45*(4), 691-699.

Vandermerwe, S., & Rada, J. (1988). Servitisation of business: Adding value by adding services. *European management journal*, *6*(4), 314-324.

Visnjic, I., Neely, A., & Wiengarten, F. (2012). Another performance paradox?: A refined view on the performance impact of servitisation. *A Refined View on the Performance Impact of Servitisation (July 4, 2012). ESADE Business School Research Paper*, (231).

Wallsten, S. (2013). *What are we not doing when we're online* (No. w19549). National Bureau of Economic Research.

Wang, Q., Hu, A., & Tian, Z. (2022). Digital transformation and electricity consumption: Evidence from the Broadband China pilot policy. *Energy Economics*, *115*, 106346.

Wang, W., Lai, K. H., & Shou, Y. (2018). The impact of servitisation on firm performance: a meta-analysis. *International Journal of Operations & Production Management*, *38*(7), 1562-1588.

Wise, Richard, and Peter Baumgartner. "Go downstream: The new profit imperative in manufacturing." *IEEE Engineering Management Review* 28.1 (2000): 89-96.

World Bank. (2023). *Digital progress and trends report*. World Bank. https://www.worldbank.org/en/publication/digital-progress-and-trends-report

World Trade Organization. (2020). *World trade report 2020: Government policies to promote innovation in the digital age*. World Trade Organization. https://www.wto.org/english/res_e/publications_e/wtr20_e.htm

Zapata, S. D., Carpio, C. E., Isengildina-Massa, O., & Lamie, R. D. (2013). The economic impact of services provided by an electronic trade platform: The case of MarketMaker. *Journal of Agricultural and Resource Economics*, 359-378.

Zhang, L., Tao, Y., & Nie, C. (2022). Does broadband infrastructure boost firm productivity? Evidence from a quasi-natural experiment in China. *Finance Research Letters*, *48*, 102886.

Zhao, S., Peng, D., Wen, H., & Song, H. (2022). Does the digital economy promote upgrading the industrial structure of Chinese cities?. *Sustainability*, *14*(16), 10235.

Zuo, G. W. (2021). Wired and hired: Employment effects of subsidized broadband Internet for low-income Americans. *American Economic Journal: Economic Policy*, *13*(3), 447-482.

Appendix

A4.Poisson regression

Since the count of firm registrations is always greater than or equal to zero, we used PPML regression to examine the relationship between the broadband access index and firm entries, exits, and stock numbers.

Table A.4.4.1. The impact of broadband on firm entry exits and stock (Possion)

	(1)	(2)	(3)
	Entry	Exits	Stock at end of year
Broadband Access Index	10.09	12.38	-74.00
	(13.52)	(13.55)	(61.90)
Constant	101.3	501.8***	4,741***
	(134.5)	(101.7)	(448.5)
Observations	1,685	1,685	1,685
R-squared	0.994	0.991	0.999
Control	YES	YES	YES
DistrictFE	YES	YES	YES
YearFE	YES	YES	YES
District	337	337	337
R2_within	0.303	0.173	0.343

Notes: Estimates are based on sample period from 1997 to 2002. District and year fixed effects are controlled. The variable is the count number level. Standard errors are in parentheses and clustered at the district level. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

Table A.4.4.1 reports the results of Poisson regressions estimating the effect of broadband access on firm entry, exits, and the stock of firms. Across all three models, the estimated coefficients for the broadband access index are insignificant, with relatively large standard errors. In Column (1), the broadband index is positively associated with firm entry, but the effect (10.09) is not significant. Column (2) reports a similar insignificant positive relationship for firm exits (12.38). Column (3) shows a large negative coefficient (–74.00) for the firm stock at year-end, but again the effect is not significant.

These results suggest that, when using the Poisson specification, there is no robust evidence that broadband access significantly affects firm entry, exit, or the total number of firms, once fixed effects and controls are accounted for.

A5. Annual Respondents Database

ARD is a statutory survey covers all sectors of the economy (except finance) since 1998. ONS provides an identifier-Inter-Departmental Business Register (IDBR) to each firm, and we will use the IDBR to combine the ARD dataset with other ONS firm-level data sources. The basic unit of production of any business is the local unit (LU), or establishment. However, the data for ARDx are collected and organised at the reporting unit (RU) level, or firm level; this reflects the smallest collection of units able to provide the financial information required. In most cases, these will be LUs carrying out the same activity. Around 95% of the RUs in the ONS data have only one LU, i.e. they are single-site businesses. (ons,2015).

A5.5 Further analysis- Broadband Intensity Effect

Since an amount of literature cannot effectively show the evidence of the impact of broadband infrastructure on firm productivity, we additionally expanded the difference in difference model interaction with broadband intensity, which is measured by the pre-event characteristics.

A5.5.1 research method

First of all, we use the physical properties of ADSL technology to measure the strength of ADSL broadband impact. Since ADSL utilizes copper wires, the length of the copper wire affects the quality and speed of ADSL signal transmission. It is the pre-trend characteristics of each firm. The distance and length of a firm from the local exchange are determined by the historical telephone network lines that were established before the introduction of broadband. This factor contributes to variations in the intensity of broadband received by each firm, especially when considering firms that have not changed their location. Typically, when the distance is within 2 kilometres, ADSL can provide high download speeds; beyond 2 kilometres, the download speed drops significantly, and the upload speed is also affected. Beyond 5 kilometres, the ADSL speed may drop to an unacceptable level. The longer the loop length, the poorer the signal quality, allowing us to utilize the distance from the company's geographical location to its corresponding local exchange as the intensity of our broadband exposure.

$$Y_{ijt} = a + \beta_{ijt}Treated_{ijt} + \theta_{ijt}Treated_{ijt} * distance_{ijt} + distance_{ijt} + \delta X_{it} + \sigma X_{jt} + \alpha_i + LA_j + Sector_\rho + Year_t + \epsilon_{ijt} \text{(A5.5.1)}$$

$Treated_{ijt}$ is an indicator for whether in year t, ADSL Broadband was activated at LA_j.

β_{ijt} still shows the treatment effect after broadband activation. distance_{ijt}represents the loop length(km) between local exchange and firm i in district j. Considering that the telephone loop is rarely straight, the loop length is closer to the actual situation, we also provide the linear distance in our appendix. The interaction terms $Treated_{ijt} * \text{distance}_{ijt}$ represent how the broadband impact changes with distance. θ_{ijt} indicates the extent to which the impact of broadband activation on firm performance changes with increasing distance. If θ_{ijt} is negative, it implies that the farther the distance, the smaller the effect of broadband activation on improving firm productivity.

And the same time, in order to estimate the dynamic effects of broadband intensity, given that the firms already meet the parallel trends condition, we extend this model to a semi-dynamic model (Canzian et al (2019) and Braghieri et al (2022)) as follows:

$$Y_{it} = \sum_{d=0}^{d=2} \theta_d \, t_{j0} \times \text{distance}_{ijt} \quad + \beta_d t_{j0} + \delta X_{it} + \sigma X_{jt} + \alpha_i + LA_j + Sector_p + Year_t + \epsilon_{ijt} \quad (A5.5.2)$$

In this model, we interact the different period after the treatment year(d=0 to d=2) with distance_{ijt}. The coefficients on these interactions θ_d are then reported for each post-activation period and the effect of Internet Exposure/intensity(distance) on firm productivity.

In these models we also control the common time shocks by adding year-fixed effects ($Year_t$); And unobservable factors of firm performance are controlled for by firm fixed effects (α_i) and additionally district level fixed effect(LA_j) . δX_{it} and σX_{jt} are firm and district covariates.We also control the sector-level fixed effect($Sector_p$). And the Standard error cluster at district level.

A5.5.2 Regression Results

Baseline regression

Table A5.5.1 presents the results for various indices of firm productivity based on model (A5.5.1). We controlled for firm-level characteristics such as firm age, foreign ownership, presence of multiple plants, and telecommunication costs. Additionally, we used initial district-level GDP per capita as a control covariate. Our results account for firm-level fixed effects, year –sector fixed effects, and district-level fixed effects.

The results in Table A5.5.1 indicate that broadband rollout alone is associated with significant improvements in labour productivity and turnover. Specifically, Treated firms show significant gains in labour productivity, with weaker positive effects on GVA-based productivity and turnover. However, these gains are mitigated by longer loop lengths: the interaction term is significantly negative for four out of five outcomes. In particular, for employment (column 2), each unit increase in loop length is associated with a 0.95 percentage point increase, suggesting that employment rises more in peripheral firms. Yet, for productivity-related outcomes, the loop length dampens the benefit. For example, the positive effect on labour productivity diminishes by 2.0 percentage points per unit increase in loop length, implying diminishing returns to broadband speed. The interaction of Treated and loop length show the broadband treatment effect decreases with the loop length. This implies that beyond 3 kilometers, the positive impact of broadband treatment becomes negligible, which are in line with the physical properties of broadband copper lines.

These findings are consistent with the interpretation that not all broadband access is equal—firms located closer to the exchange experience stronger benefits from broadband deployment. This supports the notion that the quality and intensity of digital connectivity, rather than access alone, plays a central role in translating infrastructure into performance improvements.

Table A5.5.1 simple regression

	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	**Log of Firm Employment**	**Log of Firm GVA**	**Productivity (GVA)**	**Productivity (Turnover)**
Treated	0.0127	-0.0298***	0.0345*	0.0675***	0.0440*
	(0.0256)	(0.0107)	(0.0205)	(0.0196)	(0.0251)
TreatedXLoop length	-0.00549	0.00947***	-0.0104*	-0.0200***	-0.0152**
	(0.00701)	(0.00300)	(0.00602)	(0.00582)	(0.00705)
Foreign	0.0265***	0.00914**	0.00611	-0.00327	0.0172*
	(0.00953)	(0.00421)	(0.00827)	(0.00851)	(0.00963)
Age	0.0196***	0.00742***	0.000489	-0.00618**	0.0120***
	(0.00439)	(0.00159)	(0.00266)	(0.00273)	(0.00430)
Multi-plant	0.132***	0.276***	0.104***	-0.169***	-0.143***
	(0.0172)	(0.0113)	(0.0153)	(0.0187)	(0.0178)
Lntele	0.0388***	0.0459***	0.0494***	0.00264	-0.00726
	(0.00559)	(0.00398)	(0.00784)	(0.00752)	(0.00587)
Constant	7.389***	3.762***	7.337***	3.567***	3.626***
	(0.176)	(0.0652)	(0.0770)	(0.0762)	(0.136)
Observations	82,447	82,967	69,317	69,312	82,441
R-squared	0.946	0.979	0.957	0.840	0.883
FirmFE	YES	YES	YES	YES	YES
DistrictFE	YES	YES	YES	YES	YES
YearFEXSectorFE	YES	YES	YES	YES	YES
Cluster	lad2011old1	lad2011old1	lad2011old1	lad2011old1	lad2011old1
R2_within	0.00671	0.0458	0.00629	0.00472	0.00324
District_number	377	377	377	377	377

Notes: Unbalanced panel. Robust standard errors in parentheses, adjusted for clustering at the firm level. "Loop length" is defined as the loop length between a firm and a local exchange. *p < 0.10, **p < 0.05, ***p < 0.01.

Semi-dynamic Results

We employ the semi-dynamic model (A5.5.2) to estimate the semi-dynamic effects of ADSL availability on firm performance. These effects are informative about the impact of the local BT ADSL activation policy on firms in the short term, i.e. up until two years after ADSL activation. Table A5.5.2 presents the dynamics of treatment effects: firm turnover, firm GVA, firm labour productivity shows treatment effects that increase over time in the post periods. Table 5.5.2 also sheds light on our simple regression; the weakening of Internet intensity due to distance causes the positive effects on firms to gradually diminish.

The results of our study align with the conclusion of Canzian et al. (2019), although we find a positive impact on firm labour productivity rather than the positive effect on TFP productivity reported in their findings. Additionally, our findings support the evidence for labour productivity demonstrated by Kim and Orazem (2016). In contrast to the study by DeStefano et al. (2023), which found no significant effect of ADSL Internet on firm labour productivity (based on turnover as an output measure), our results show a positive impact. They employed a spatial discontinuity approach based on the maximum distance of broadband availability within the UK. The location of the boundary was determined by the boundary of the local exchange area of broadband-enabled exchanges, up to a maximum distance of 5.5 kilometres, which is the limit at which firms could receive an ADSL broadband connection. However, our results indicate that the impact of broadband becomes nearly zero beyond 3 kilometres.

Table A5.5.2 semi-dynamic model

	(1)	(2)	(3)	(4)	(5)
	Log of Firm Turnover	Log of Firm Employment	Log of Firm GVA	Productivity (GVA)	Productivity (Turnover)
Year of Activation	-0.0250	-0.0301***	0.0341*	0.0620***	0.00612
	(0.0247)	(0.00946)	(0.0188)	(0.0181)	(0.0246)
Year of ActivationXloop length	0.00398	0.00987***	-0.00991*	-0.0191***	-0.00608
	(0.00665)	(0.00266)	(0.00566)	(0.00546)	(0.00672)
1 year after Activation	0.0625*	-0.0357**	0.0252	0.0745**	0.0998***
	(0.0331)	(0.0158)	(0.0317)	(0.0326)	(0.0323)
1 year after ActivationXloop length	-0.0161*	0.0101**	-0.00826	-0.0195**	-0.0264***
	(0.00914)	(0.00439)	(0.00894)	(0.00885)	(0.00916)
2 year after Activation	0.0754*	-0.0172	0.0529	0.0788*	0.0954**
	(0.0451)	(0.0214)	(0.0486)	(0.0462)	(0.0458)
2 year after ActivationXloop length	-0.0189	0.00671	-0.0169	-0.0239*	-0.0263**
	(0.0127)	(0.00622)	(0.0137)	(0.0129)	(0.0129)
Foreign	0.0265***	0.00913**	0.00612	-0.00332	0.0171*
	(0.00952)	(0.00421)	(0.00828)	(0.00852)	(0.00962)
Age	0.0196***	0.00742***	0.000476	-0.00618**	0.0121***
	(0.00440)	(0.00159)	(0.00266)	(0.00273)	(0.00431)
Multi-plant	0.132***	0.276***	0.104***	-0.169***	-0.143***
	(0.0171)	(0.0113)	(0.0153)	(0.0187)	(0.0178)
Lntele	0.0387***	0.0459***	0.0494***	0.00260	-0.00731
	(0.00560)	(0.00398)	(0.00783)	(0.00752)	(0.00587)
Constant	7.413***	3.764***	7.338***	3.571***	3.649***
	(0.174)	(0.0660)	(0.0784)	(0.0794)	(0.134)
Observations	82,447	82,967	69,317	69,312	82,441
R-squared	0.946	0.979	0.957	0.840	0.883
FirmFE	YES	YES	YES	YES	YES
DistrictFE	YES	YES	YES	YES	YES
YearFEXSectorFE	YES	YES	YES	YES	YES
Cluster	lad2011old1	lad2011old1	lad2011old1	lad2011old1	lad2011old1
R2_within	0.00693	0.0459	0.00631	0.00475	0.00346
District_number	377	377	377	377	377

Notes: Unbalanced panel. Robust standard errors in parentheses, adjusted for clustering at the firm level. "Activation year", "1 Year after Activation", and "2 Years after Activation" are indicator variables set equal to one if a district gained ADSL access 0 and respectively 1 and 2 years after. "Loop length" is defined as the loop length between a firm and a local exchange. *p < 0.10, **p < 0.05, ***p < 0.01.

A.6 The importance of the predicted increase in service revenue.

Table.A.6.1 Regression on services growth and good_growth

	(1)
	Service_growth
Good_growth	-0.572***
	(0.0561)
Constant	-0.0512***
	(0.0151)
Observations	8,606
R-squared	0.012

***significant at 1 percent, **significant at 5 percent, *significant at 10 percent

Table A.6.4 Relating Services Relative to Goods Sales with Firm Outcomes

	(1)	(2)	(3)	(4)
	Log of Turnover	Log of Employment	Log of Wage	Log of labour Productivity
Ln(Ratio of service/goods revenue)	0.0711***	0.0650***	0.00824***	0.00875***
	(0.00861)	(0.00733)	(0.00237)	(0.00280)
Observations	22,493	22,592	21,711	22,204
R-squared	0.142	0.124	0.118	0.090

Notes: Year and firm fixed effect included. Standard errors are clustered at the district level and are in parentheses. ***significant at 1 percent, **significant at 5 percent, *significant at 10 percent.

An alternative way of highlighting the importance of the predicted increase in service production is to look at associations with other variables of interest, such as wages or employment. In Table A.6.4, we look at the services/goods production effect on different firm outcomes. We control the firm-level fixed effect, year fixed effect and sector fixed effect. The results show that the services ratio grows with higher firm turnover and employment and also increases firm wage and labour productivity. The results show that a 1 percent increase in the service-to-goods ratio is associated with an approximate 0.08 percent increase in firm-level total sales, a 0.065 per cent increase in employment, a 0.008 percent increase in wages, and a 0.008 percent increase in labour productivity. Recalling our earlier results, the service-to-goods ratio increased by approximately 130% in firm with local broadband improvement (assuming broadband penetration from 0 to 1) compared to firm without broadband. We can use this figure along with the above correlations, to compute the implied changes in firm-level outcomes. For example, according to our estimates in column (2), the service ratio increased by 138% due to the rise in broadband penetration, which is associated with an 8.97% increase in firm-level employment (138 X9.09 = 8.97%). The last row of Table A.6.4 also reports similar implied changes for other variables. Of course, we caution that these calculations are based on simple correlations and do not imply a causal relationship.