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Broadband Shocks, TFP Growth and Polarisation of European Firms

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Abstract

Is the roll-out of (fast)broadband connections a driver of firms' total factor productivity (TFP) growth in the European Union? Does broadband generate convergence or polarisation? In this regard, which firms benefit most from a broadband connection and is the traditional divide between rural and urban deployment areas important? To answer these questions, we estimate the effects of broadband coverage shocks on individual firms' TFP growth, exploiting broad firm-level coverage from the ORBIS dataset and a relatively long time span (2011–2022) over which broadband shocks are observed. Broadband shocks permanently raise firms' TFP, but their effect is uneven: fast-growth firms improve their relative position. They are more beneficial for the TFP of firms in non-digital sectors, supporting the view that internet connectivity is a general-purpose technology. Firms in urban areas are also better equipped to benefit from increased broadband connectivity. TFP responses to fast-broadband shocks are almost muted.

Keywords: TFP, Broadband, firm performance
JEL codes: L25, D24, L9

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1 Introduction

The Information and Communication Technology (ICT) revolution has reshaped the world economy, spurring economic growth in several developed and developing economies (Jorgenson and Vu, 2016). All this would have been unthinkable without internet access, explaining why policymakers have increasingly focused on the deployment of broadband as a tool to foster innovation and growth (Kruger (2009); European Commission (2010); Hauge and Prieger (2015)). Following the launch of the post-COVID NGEU program, the European Union has identified ambitious targets in high-speed connectivity development, which are supported by large public investments (Darvas et al. (2021); European Commission (2021)).

Despite the enthusiasm of policymakers, the empirical evidence on the effects of broadband deployment on firms' productivity is still controversial (see our discussion below). This paper reconsiders the issue, investigating the relationship between broadband coverage and TFP growth in a large panel of European firms. A distinctive feature of our dataset is the combination of broad firm-level coverage and a relatively long time horizon (2011–2022), over which the effects of broadband connectivity are evaluated.

Our empirical strategy unfolds in three steps. First, we estimate firm-level TFP using production functions identified through the nonparametric method proposed by Gandhi et al. (2020). For this purpose, we leverage the Orbis global database provided by Bureau van Dijk, which offers a comprehensive and reliable representation of European national economies (see Kalemli-Özcan et al. (2024)).

Second, we identify (fast)broadband shocks. We exploit two connectivity measures that differ in the expected average download speed, which is defined as broadband and fast broadband, and denote the percentage of households in a EU NUTS3 region with access to (fast)broadband connections. Our dataset, therefore, gathers information on internet connectivity for 1,010 regions over 12 years. While we consider the breadth of our dataset (number of firms, regional dimension of internet coverage) an appealing feature of our study, this setting presents methodological challenges, particularly in defining an appropriate identification strategy. Standard difference-in-differences methods, frequently used in the literature, are not applicable here, as they typically rely on discrete treatment events confined to specific episodes in certain countries or regions. Further, standard instrumental variables, such as a firm's distance from the closest node (see our discussion in section), cannot be exploited given the aggregation of the broadband coverage index at the NUTS3 level. We opted for an alternative identification strategy, where (fast)broadband shocks are recovered from a dynamic panel estimator that predicts (fast)broadband coverage based on its own past values and several controls.

Finally, in the third step, we assess the impact of broadband coverage shocks on TFP growth using the local projections method (Jordà, 2005), allowing us to trace these shocks' dynamic effects over time.

Related literature and contribution. Studies using aggregate data typically identify a positive effect of broadband diffusion on GDP growth both in the US (Gillett et al. (2006); Crandall et al. (2007); Holt and Jamison (2009); Kolko (2012)) and across countries (Crandall et al. (2007); Gruber et al. (2014); Castaldo et al. (2018); Koutroumpis (2019); Briglauer et al. (2021)). There are, however, some notable exceptions. Mayer et al. (2020) find an insignificant response of GDP per capita to broadband speed in OECD countries between 2008 and 2012. Ford (2018) shows that the positive effects documented in Crandall et al. (2007) do not survive if one controls for endogeneity. De Clercq et al. 2023 estimate the effects of broadband on aggregate economic growth in the NUTS3 European regions between 2011 and 2018, obtaining contradictory results. Low-speed broadband access does increase growth, but the effect is weaker in rural areas. By contrast, the positive effects of high-speed broadband can only be observed in rural areas.

Concern for potential endogeneity has induced researchers to turn to granular data. Firm-level studies have led to inconclusive results. Using panel data for a large sample of firms from the Netherlands (2002–2005) and the UK (2001–2005) in the manufacturing and service sectors, van Leeuwen and Farooqui (2008) argue that connectivity raises capital deepening but not TFP. Grimes et al. (2012) found that a broadband connection raises firm productivity in a sample of New Zealand firms. Bertschek et al. (2013) found that ADSL adoption does not increase labour productivity in German firms. Haller and Lyons (2015) cannot find any significant effect of broadband adoption on firms' productivity in a sample of Irish firms. DeStefano et al. (2018) found that broadband connectivity significantly impacts firms' scale rather than their productivity in the UK. Recent studies have focused on the impact of increasing broadband speed. Fabling and Grimes (2021) found that ultrafast broadband adoption (UFB) increased the productivity of New Zealand firms over the 2010–2016 period. Cambini et al. (2023) document the positive effect of UFB on the productivity of Italian firms. Gillett et al. (2006) obtains similar results for Spanish firms.

Another strand of literature focuses on the unequal access to broadband between urban and rural areas (see Mack et al. (2024) and references cited therein). DeStefano et al. (2023) exploit geographical discontinuities in broadband availability across the UK to identify the causal effects of broadband access on firms on both sides of this divide. Consistent with DeStefano et al. (2018), they find that the only effect concerns size, favouring urban firms. By contrast, Canzian et al. (2019) show that connection upgrades are associated with firms' increased total factor productivity in the rural and sparsely populated areas in the Italian Province of Trento. Duvivier and Bussière (2022) investigated the impact of ultrafast broadband on business startups in French rural municipalities between 2013 and 2018, finding that positive effects are limited to municipalities with good initial economic and demographic conditions.

Our paper also relates to the literature investigating the sectoral effects of broadband access. Extensive literature has examined the efficiency-enhancing effect of digitisation based on internet access (Goldfarb and Tucker (2019)). Furthermore, the possibility of internet access has been defined as a General Purpose Technology, which enables innovations and the spread of innovations across disparate sectors (Agrawal et al. (2023)). Duso et al. (2021) study the impact of broadband availability on German firms' TFP in different sectors between 2010 and 2015. They cannot detect a productivity increase in manufacturing, but improvements are significant in many service sectors. Sarachuk and Mißler-Behr (2022) focus on new business creation in Germany, finding that the shift from broadband connectivity to ultrafast speed has a positive and significant effect only for ICT firms. Chen et al. (2023) focus on sectoral net entry rates in the US. Broadband causes net establishment gains in construction and professional services. Net establishment gains in financial services, information, arts, and entertainment were observed only in urban areas. Net establishment losses were experienced in the urban retail and rural manufacturing sectors. Broadband also leads to a net reallocation of educational services establishments from rural to urban areas.

Our contribution stands out along several dimensions. First, our TFP estimation method is essentially agnostic about the functional form of the production function. It relies on output elasticities estimated at the firm level, rather than estimating production function coefficients, and is less prone to measurement error (see Anderton et al. (2023) and references cited therein). Second, our dataset encompasses a large number of firms, and we present results regarding both the average effects of increasing broadband coverage in continental Europe and the country-specific responses of TFP. We provide EU-wide results that allow us to condition the effects of connectivity shocks on the sectoral specialisation of firms (manufacturing vs services, digital intensity), on the firms' structure (size, leverage, etc.), and some distinctive features of the regions hit by the shock (the degree of urbanisation/rurality, connectivity, GDP per capita). Finally, we present a set of country-specific results, focusing on the countries that contribute relatively more observations to our dataset of estimated TFP growth.

In a nutshell, our results. First, broadband shocks trigger a positive cumulative response of

TFP growth. Second, high-TFP growth firms benefit relatively more than laggard ones from broadband shocks. Third, analysis of sector-specific effects reveals that non-digitally intensive sectors benefit the most. Fourth, urbanisation is the only regional effect that increases the strength of the TFP response. Fifth, more profitable firms achieve larger TFP increases. Sixth, at the national level, we observe substantial heterogeneity. Countries like Italy and Spain, which are typically considered laggards in digital transformation, achieve relatively large TFP gains. By contrast, we cannot detect significant gains for France. Finally, evidence about the TFP gains from fast broadband shocks is tenuous. This is consistent with previous contributions. It is also important to emphasise that the broadband roll-out occurred at different times depending on the download speed. While broadband was deployed in most regions during the early years of our sample, fast broadband mainly became available towards the end of the period under analysis. Given the observed substantial lags between the broadband shocks and the estimated TFP gains, one possible rationalisation of this result could be that our sample period is still too short to identify the potential gains from fast broadband roll-out.

The remainder of the paper is organised as follows. Section 2 describes our firm's data set and the two indices of broadband coverage. Section 3 presents TFP estimates. The estimated effects of broadband shocks are reported in section 5. Section 6 concludes.

2 Data description

2.1 Firms

Firms' balance sheet data are the basis for TFP calculations. These are obtained from Orbis Historical, a database provided by Moody's/Bureau van Dijk, which includes firm-level harmonised financial and ownership information for private and publicly listed firms in a large number of countries and an extended period. The data derive from national business registers, with coverage varying depending on country-specific legal and administrative filing requirements. Kalemli-Özcan et al. (2024) have shown that Orbis has good national representativeness in Europe, even for small private firms. After merging it with broadband data, we obtain a dataset of approximately 6.5 million firm-level observations in 21 European countries,[1] 1010 NUTS3 regions, for 2011-2022. Due to the information requirements of our TFP estimation procedure described below, we limit our sample to firms that provide data for at least four

[1]Covered countries are Austria, Belgium, Bulgaria, Croatia, Denmark, Estonia, Finland, France, Germany, Hungary, Italy Luxembourg, Norway, Poland, Portugal Romania, Slovakia, Slovenia, Spain, Sweden.

consecutive years.

Table 6 describes the country distribution of our firm-level data, detailing the number of firm-year observations and the number of NUTS3 regions covered.

2.2 Broadband and population data

Following de Clercq et al. (2023), broadband data was obtained from Point Topic (2024), which provides granular information on broadband access at the NUTS3 level from 2011 to 2022.[2] For each region, we use two measures: the share of households with broadband access capable of realistically achieving download speeds of at least 30 Mbit/s and 100 Mbit/s, respectively. We refer to the former as broadband (BB30) and the latter as fast broadband (BB100).

These measures are complemented by additional variables at the regional level, such as population density, GDP per capita, and the proportion of the population residing in rural areas.

Figures 1 and 2 document the increase in (fast) broadband coverage across the NUTS3 regions. Figures 3, and 4 document the strong convergence in the degree of broadband coverage, with regions lagging behind in 2011 showing the highest increase in coverage. Evidence for fast broadband coverage is qualitatively similar but less intense. (see Figures 5 and 6). Finally, Figures 7 and 8 map the distribution of the population living in rural/urban areas in the NUTS3 regions.

(a) 2011 (b) 2022

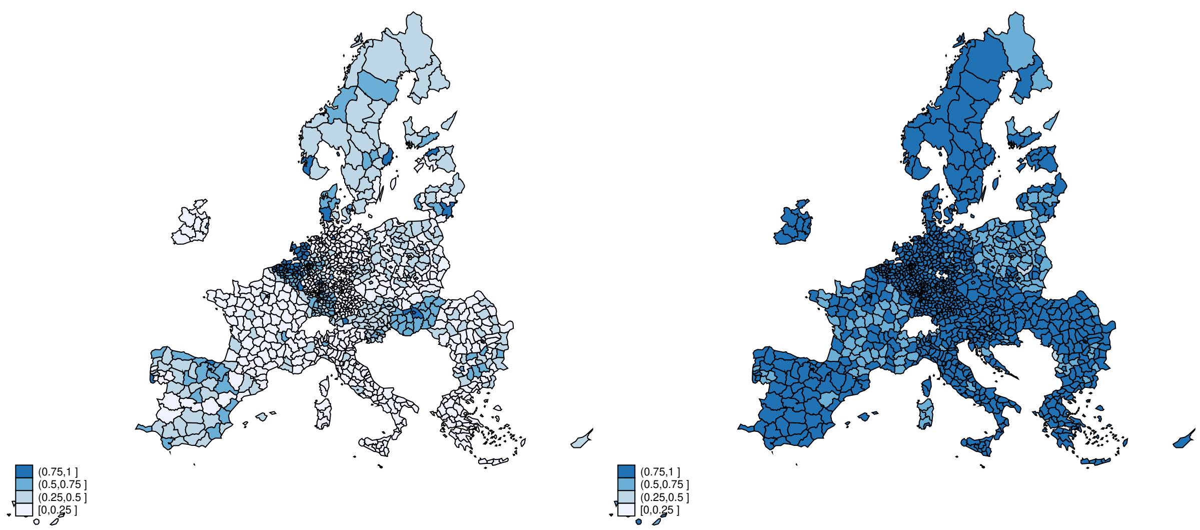


Figure 1: Broadband 30 Mbps coverage in Europe (2011 to 2022)

[2]NUTS is the European regional classification taxonomy which defines three major layers. NUTS1: major macro regions. NUTS2: regions (those generally used by the EU for conducting regional policies). NUTS3: small regions.

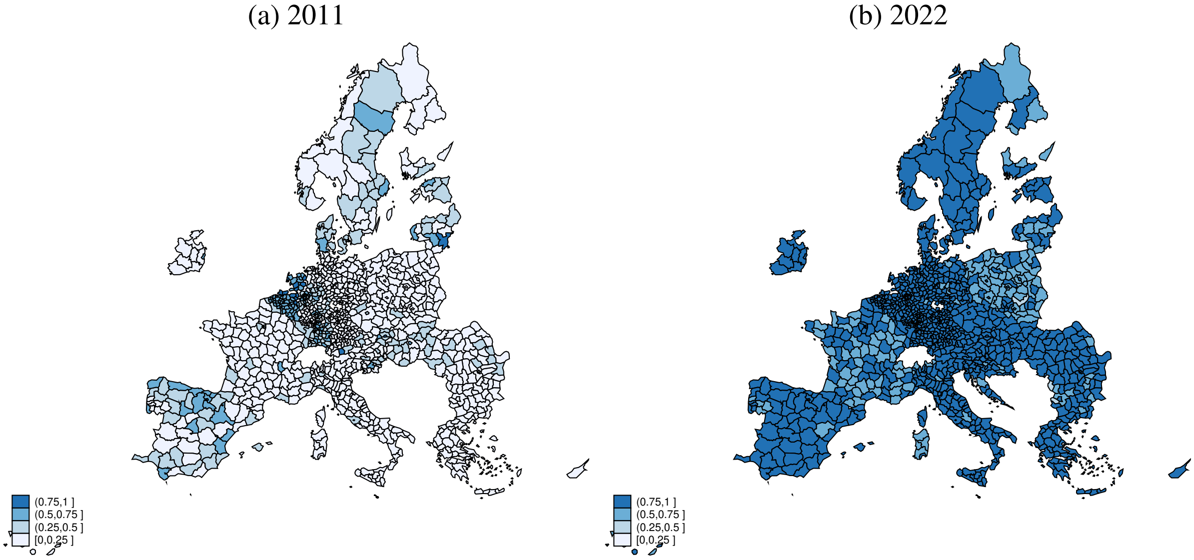


Figure 2: **Broadband 100 Mbps coverage in Europe (2011 to 2022**

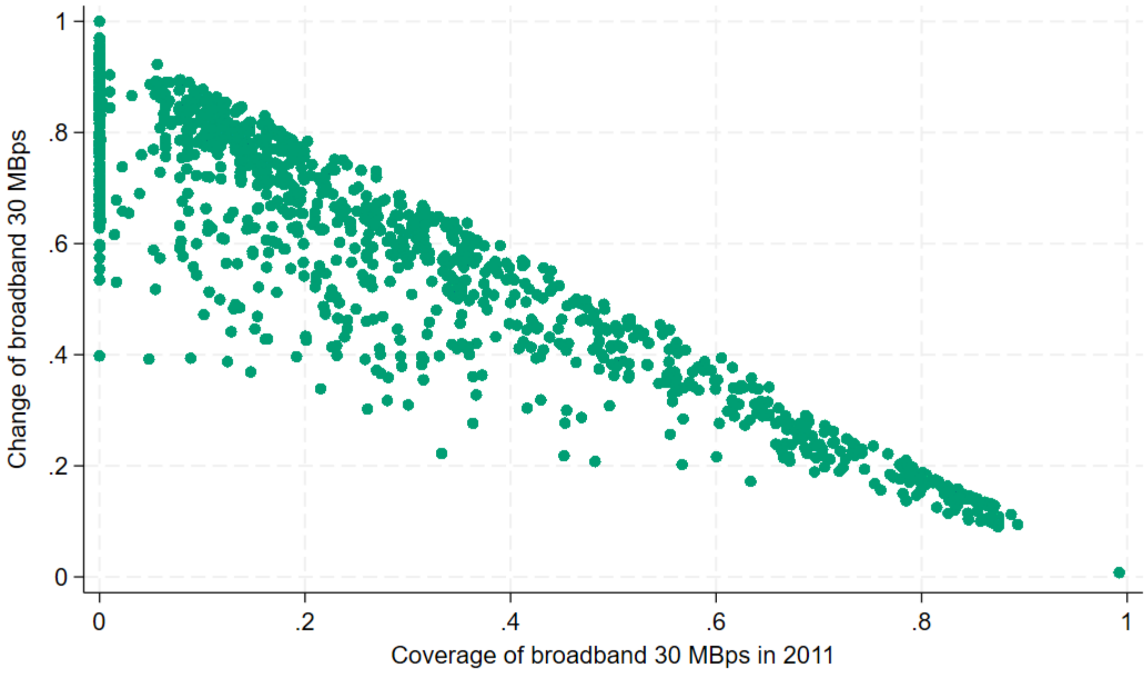


Figure 3: Broadband convergence (30 Mbps), EU NUTS3 regions

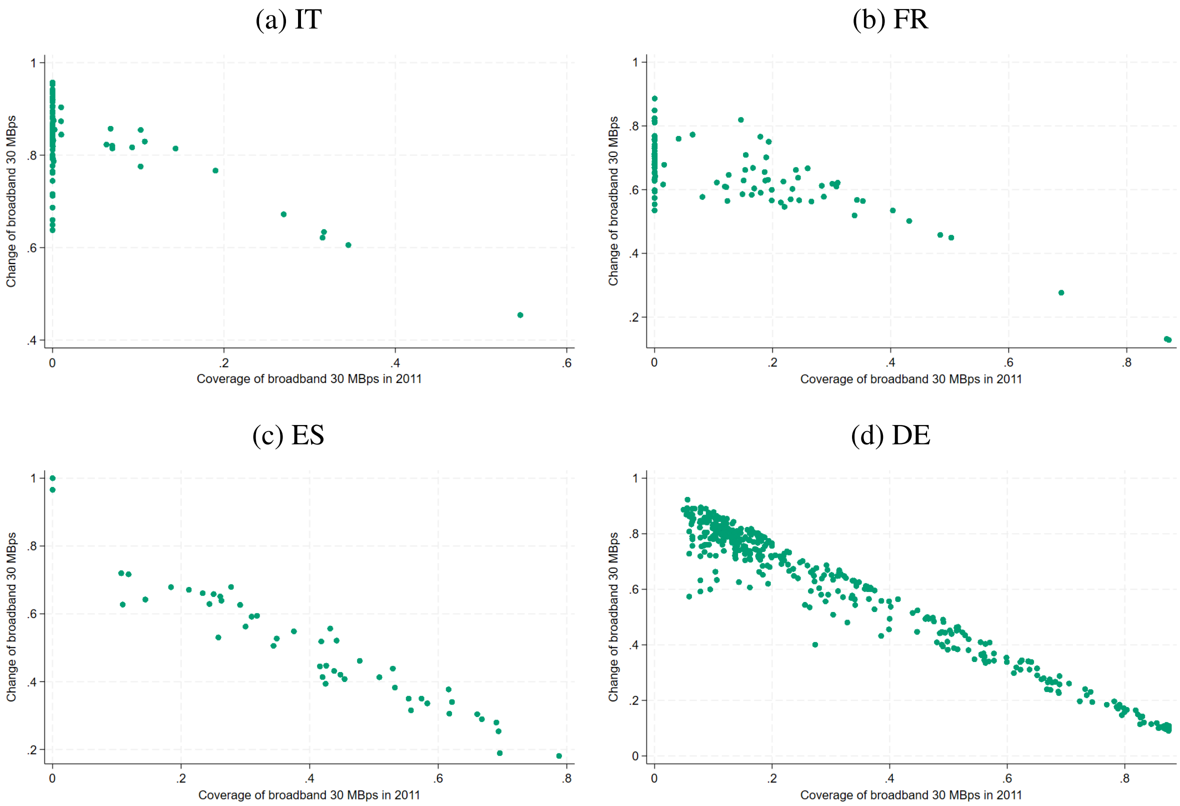


Figure 4: Selected countries. Broadband convergence (30 Mbps), NUTS3 regions

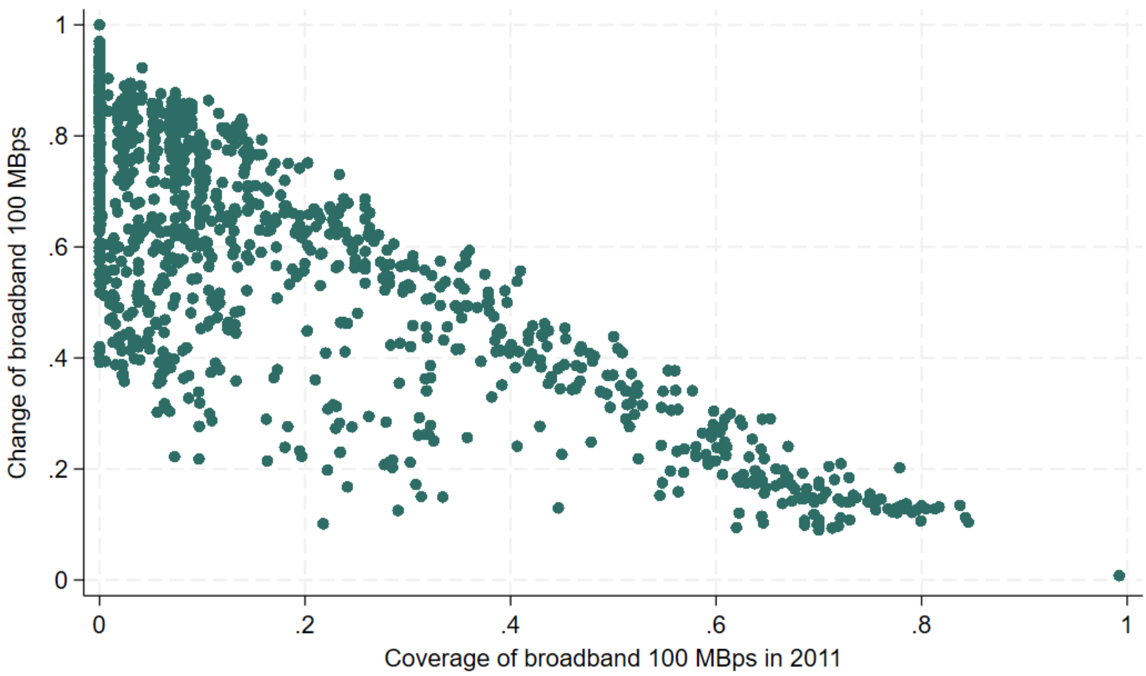


Figure 5: Broadband convergence (100 Mbps), EU NUTS3 regions

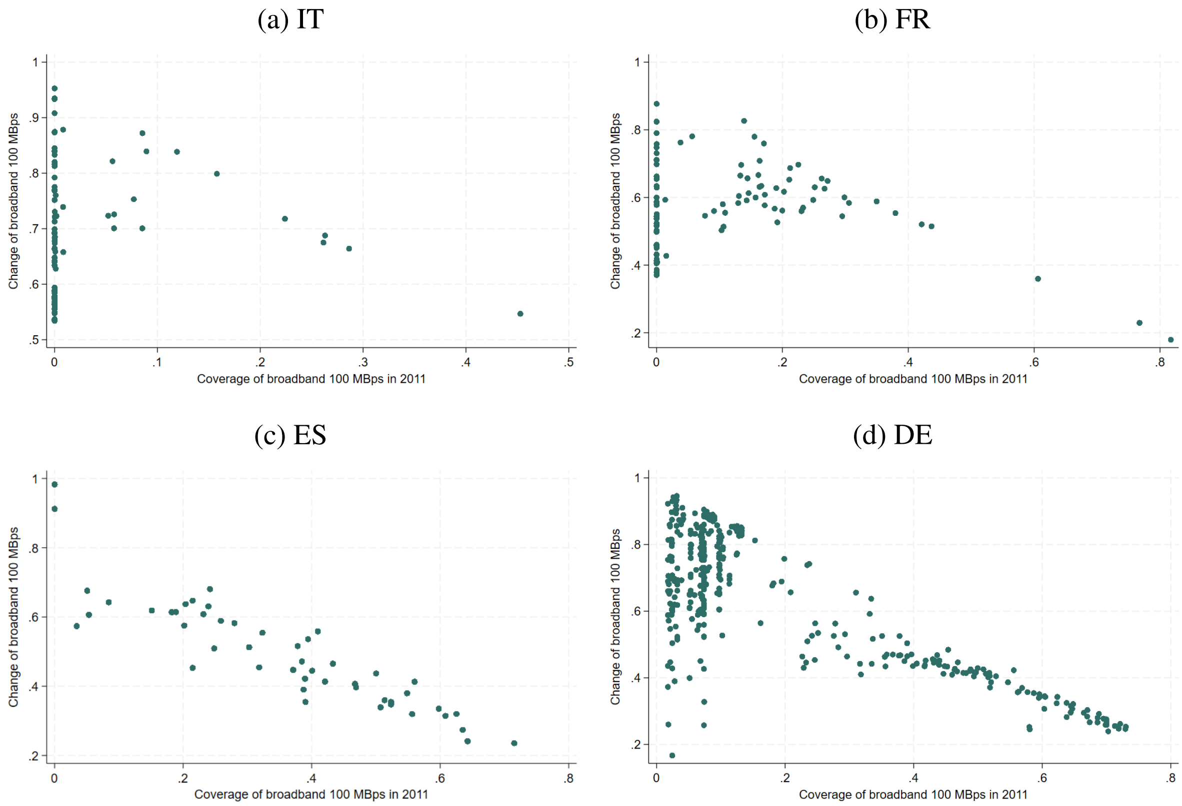


Figure 6: Selected countries. Broadband convergence (100 Mbps), NUTS3 regions

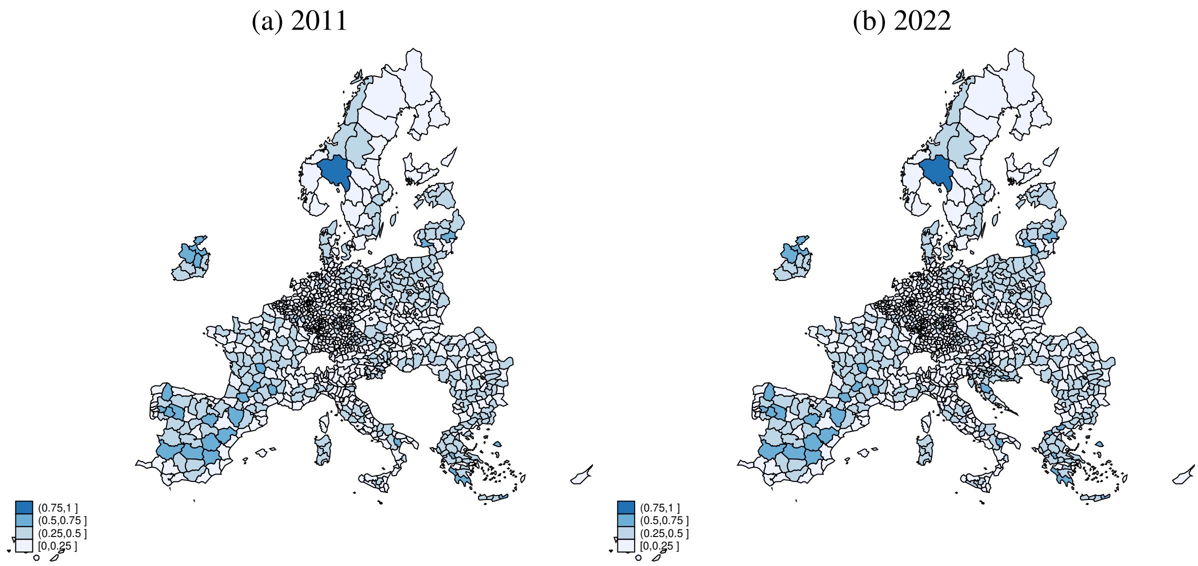


Figure 7: Percentage of households in NUTS3 regions where population density is below 100 people/km^2)

(a) 2011 (b) 2022

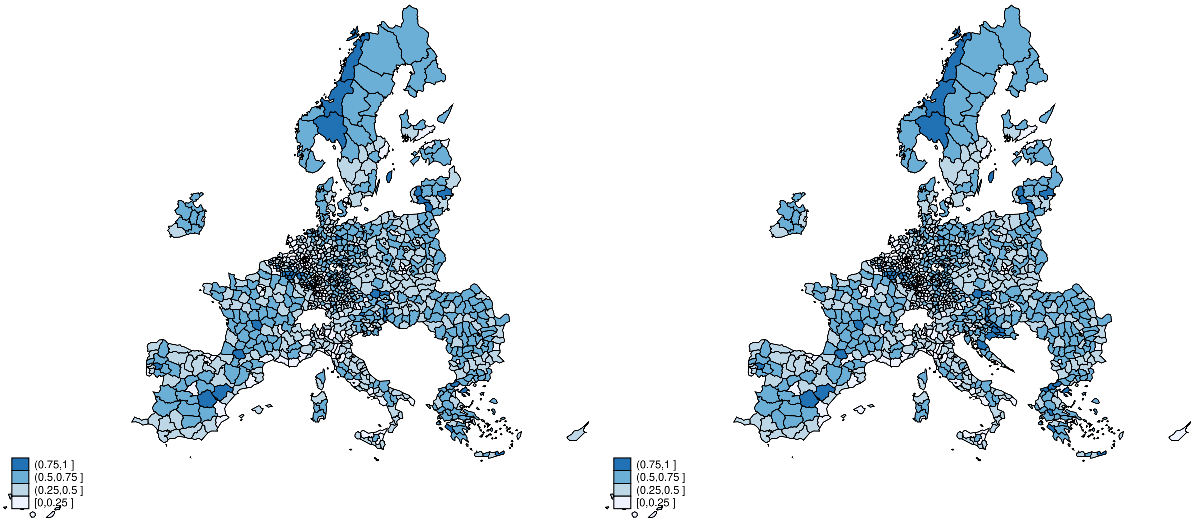


Figure 8: Percentage of households in NUTS3 regions where population density is above 600 people/km^2

3 TFP estimates

There is a longstanding tradition of recovering firms' TFP residually from estimated production functions under the assumption of Hicks-neutral technological change:

$$y_{i,s,r,c,t} = F_s(k_{i,s,r,c,t}, l_{i,s,r,c,t}, z_{i,s,r,c,t}) + tfp_{i,s,r,c,t} \tag{1}$$

$$tfp_{i,s,r,c,t} = \omega_{i,s,r,c,t} + \nu_{i,s,r,c,t} \tag{2}$$

where y, k, l, z, define the logs of output, capital, labour, and material inputs in real terms, whereas subscripts i, s, r, c, t denote firm, NUTS3 region, country, and time. The tfp term is the sum of ω, which is known to the firm at time t, when the optimisation problem is solved, and an unpredictable component ν. The term ω is assumed to follow a Markovian process. The problem in estimating the production function above is that the firm chooses both inputs k_t and l_t after it has (partially) observed ω_t, making any estimate of the coefficients for k and l inconsistent.

Most of the literature has attempted to address this problem by using information about firms' first-order conditions, where each input's cost or revenue shares are linked to the respective input elasticities. In particular, given the parametric functional form of the production function, the first-order conditions can be used to obtain the parameter restrictions necessary for identification (Ackerberg et al., 2015; Levinsohn and Petrin, 2003).

In this paper, we follow a recent contribution by Gandhi et al. (2020), who provide a novel approach to nonparametric gross output production function identification. More specifically, they show that it is possible to obtain the firm's tfp through a two-step procedure. First, the output elasticity of intermediate materials is estimated using a non-parametric (sieve) method. Second, the remaining parameters of the production function are retrieved from another nonparametric regression where lagged inputs, used as instruments, are sufficient to identify the production function nonparametrically and to compute the tfp term.

The advantage of this approach is that it does not rely on a rich time series panel dimension as a source of identification; therefore, it can be helpful when applied to datasets with large N and small T, such as ours. There are two caveats. First, the assumption of a uniform production function necessitates the estimation of separate production functions for each 4-digit industry. Second, using lagged inputs as instruments implies that our dataset must have firm-specific information spells of at least four consecutive years.

Table 1 displays the mean value and growth of our estimate for the available sample.

Country	ln(TFP)		
	Av. growth	Mean	Median
Austria	.034	9.367	8.892
Belgium	.008	9.335	8.759
Bulgaria	.0238	7.189	7.480
Croatia	.0200	9.245	8.964
Denmark	-.011	9.326	9.249
Estonia	.038	7.77	7.658
Finland	.005	9.590	9.219
France	.057	8.946	8.730
Germany	.006	10.756	10.111
Hungary	-.010	7.395	7.345
Italy	-.004	8.063	8.249
Latvia	.029	5.561	5.177
Luxembourg	.025	15.466	11.730
Norway	.025	10.091	10.014
Poland	.013	10.017	9.855
Portugal	-.003	8.450	8.306
Romania	.040	6.307	6.294
Slovakia	.018	9.583	9.444
Slovenia	.017	9.409	9.243
Spain	-.005	8.759	8.653
Sweden	.001	8.444	8.399
Total	.008	8.337	8.359

Table 1: TFP Estimates

4 Estimating the effects of broadband connectivity

Estimates of the effects of broadband on firms' productivity are potentially affected by endogeneity concerns. For example, local economic shocks may simultaneously influence both the decision to expand broadband coverage within a given area and the total factor productivity (TFP) growth of local firms. Conversely, firms' TFP growth may itself drive changes in broadband deployment, thus raising concerns about reverse causality. The core intuition behind this issue is that supplying broadband connectivity involves substantial fixed costs.

One standard solution to this problem is identifying instrumental variables and employing a two-stage estimation strategy, instrumenting the broadband connectivity variable with a measure of geographical broadband availability that typically raises the cost of broadband deployment. Examples include the average slope of the local terrain, as in Kolko (2012), the closeness to pre-existing fixed-line telephony and cable TV networks, as in Czernich et al. (2011), the distance of each municipality from the telecommunication networks' closest node, as in Haller and Lyons (2015) and Cambini et al. (2023). These instruments are particularly effective when the analysis is conducted at a granular territorial level, such as municipalities. However, acquiring comparable instruments across the broader spatial scale examined in this study presents significant challenges. Aggregating municipal-level data to the NUTS3 level may introduce substantial measurement error and heterogeneity, thereby complicating identification. Moreover, these geographic instruments are time-invariant, which limits their ability to capture the dynamic effects of broadband coverage over extended periods.[3] One alternative, often adopted in regional growth regressions, is to use the System GMM method developed by Arellano and Bover (1995) and Blundell and Bond (1998), which relies on first differencing the dynamic panel equation regression and using the lagged regression equation (in levels) to instrument the variables in the differenced equation. Unfortunately, it would be hard to instrument broadband coverage using a levels equation that features firm-specific variables. Therefore, we opted for a radical alternative, aiming to identify broadband shocks residually from the following dynamic model.

$$BB_{j,r,t} = \beta_0 + \beta_1 BB_{j,r,t-1} + \beta_2 PopDens_{r,t} + \beta_3 GDPpc_{r,t} + \beta_4 TFPG_{r,t} + \gamma_t + \Lambda_{r,c,t} + \epsilon_{j,c,r,t} \quad (3)$$

where BB is an index of broadband coverage, *j,c,r,t* respectively define the speed of

[3] Studies relying on this approach must incorporate exogenous time effects.

connectivity (30 or 100 Mbps), the country, the region, and time; $PopDens$, $GDPpc$ and $TFPG$ denote population density, GDP per capita in PPP standards, and regional TFP growth recovered from our estimates of firm TFP growth.[4] Finally, Λ denotes a vector of region, country, and time fixed effects. In our model, the inclusion of previous-year BB coverage aims to eliminate predictable patterns of broadband coverage expansion, whereas endogeneity concerns motivate the inclusion of the controls $PopDens$, $GDPpc$ and $TFPG$. From the estimates of (3), we recover the broadband forecast error ϵ^{BB}, which we shall use as a regressor in our TFP local projections, equation (4), reported below. Table 2 and Figure 18 in the Appendix provide some descriptive statistics for the relevant variables and plot the distribution of ϵ^{BB}.

Having obtained an exogenous source of variation of Broadband, we estimate impulse responses using the following local projections at annual frequency (see Jordà and Taylor (2025)).

$$\sum_{j=0}^{h} TFPG_{i,c,r,t+h} = \alpha_h + \beta_h \sum_{j=0}^{h} \epsilon^{BB}_{j,c,r,t} + \Gamma_h X_{i,j,c,r,t} + \Lambda_{i,r,s,c,t} + \xi_{i,r,c,t+h} \tag{4}$$

where $TFPG_{i,r,c,t+h}$ defines TFP growth of firm i in contry c, region r, at time $t+h$, $h = 0, ..., 4$; X is a vector of controls, including three lagged values of ϵ^{BB},[5] and some firm-specific controls evaluated at time t: leverage ($(long\ term\ debt + loans)/total\ assets$), size ($\log(1 + number\ of\ employees)$) and profitability ($ebitda/total\ assets$). The regression is saturated by firm, region, sector, country, and year dummies included in the vector $\Lambda_{i,r,s,c,t}$.[6] *Mutatis mutandis*, condition 4 is equivalent to the TFP models estimated in Levine and Warusawitharana (2021) and Cao et al. (2023).[7]

One appealing feature of local projections is that they can easily accommodate non-linearities in the effects of broadband shocks on firms' TFP growth, by incorporating interaction terms or smooth transition functions to analyse how the impact of a shock varies across different economic conditions or states (see Auerbach and Gorodnichenko (2013). Tenreyro and

[4]The variable is therefore the average TFP growth of the region as measured from TFP firm level estimates described in the previous paragraph. Average TFP is constructed by weighting firms by sales.

[5]The lag structure has been chosen using the Bayesian Information Criterion (BIC), as shown in table 5.

[6]As pointed out in Jordà and Taylor (2025), in Local Projection estimates, potential correlation across individual units is a source of concern, in addition to the moving-average structure of the residuals in the time-series dimension. Researchers often compute Driscoll-Kraay robust standard errors (Driscoll and Kraay (1998)). This method is particularly appropriate when the T dimension of the dataset is relatively large. In our dataset, T is rather short and N is very large. We therefore opted for clustering errors at the NUTS3 level.

[7]Condition 4 is a growth regression, and the firm fixed effect in the vector Δ captures the firm's TFP idiosyncratic growth trend.

Thwaites (2016), Colombo et al. (2024)). As a general rule, in the following, we will use interaction terms when dealing with discrete/categorical variables and smooth transition functions when dealing with continuous variables. More specifically, for smooth transition functions, we shall add to the equation (4) one additional term $\eta_h \epsilon^{BB}_{j,c,r,t} Z_i$, where Z defines the state variable of interest. Smooth transitions are estimated as follows:

$$\sum_{j=0}^{h} TFPG_{i,c,r,t+h} = \alpha_h + F(z_i)\beta_h^L \sum_{j=0}^{h} \epsilon^{BB}_{j,c,r,t} + (1 - F(z_i))\beta_h^H \sum_{j=0}^{h} \epsilon^{BB}_{j,c,r,t} + \Gamma_h X_{i,r,t} + \Lambda_{i,r,s,c,t} + \xi_{i,r,c,t+h} \quad (5)$$

where β_h^L and β_h^L respectively characterise the estimated effects of the broadband shocks for the lower(upper) tail of the distribution of Z, $z_i = \frac{Z_i - Z^{AV}}{\text{SD}(Z)}$ defines the normalised deviation of Z_i from its average value and $F(z_i) = \frac{\exp(-\gamma z_i)}{1+\exp(-\gamma z_i)}$.[8] $F(z_i)$ can be interpreted as the probability that firm *i* is associated with $z \leq z_i$. The parameter γ controls the smoothness of the transitions from β_h^L to β_h^L, with larger values associated with immediate switches, while smaller ones imply a smoother transition. [9]

5 Results

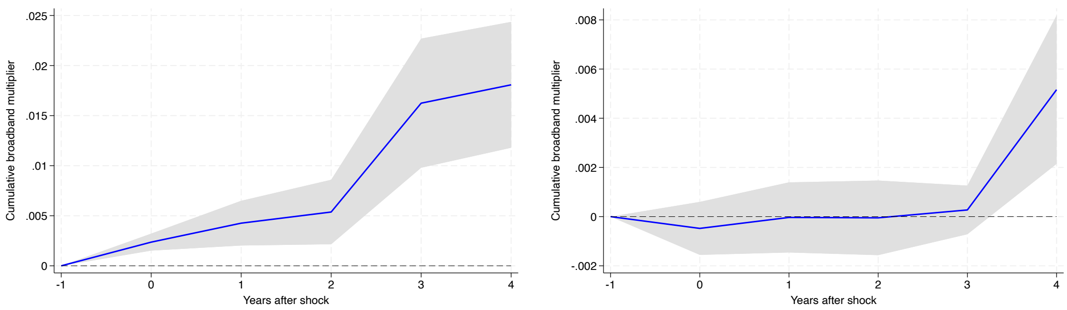
This section presents our results on how internet connectivity affects cumulative TFP growth, $\sum_{h=0}^{4} TFPG_h$, over up to five years. We report impulse responses to a one standard deviation broadband coverage shock at annual frequency, based on the local projection approach in (4) and (5).[10] We provide EU-wide results that allow us to condition the effects of connectivity shocks on the sectoral specialisation of firms (manufacturing vs services, digital intensity), on the firms' structure (size, leverage, etc.), and some distinctive features of the regions hit by the shock (GDP per capita, the degree of urbanisation/rurality). Finally, we present a set of country-specific results, focusing on the countries that contribute relatively more observations to our dataset of estimated TFP growth.

To begin with, Figure 9 displays IRFs obtained from estimates of (4) for 30 Mbps (panel a) and 100 Mbps (panel b) download speed. The overall cumulative response to a one standard

[8]Note that z_i is normalized to have zero mean and a unit variance. To reduce endogeneity, due to the potential response of Z to broadband shocks, we consider the average size of Z_i over the sample period.

[9]As stressed by Auerbach and Gorodnichenko (2012), it is difficult to identify the curvature and location of the transition function in the data, and γ, therefore, must be calibrated. We choose an intermediate value and set $\gamma = 7$, but the results (available upon request) are robust to alternative values.

[10]Figures show 95 per cent confidence bands.



(a) Broadband (30 Mbps) (b) Fast broadband (100 Mbps)

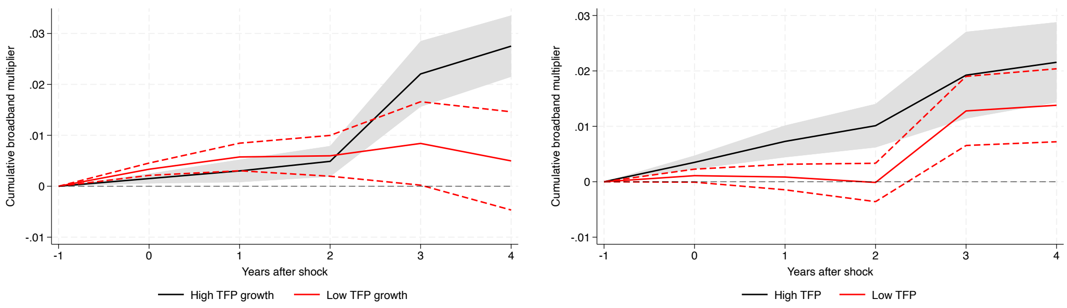
Figure 9: Main broadband effect

The figure shows the cumulative impulse response functions and the 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock.

deviation broadband coverage shock at annual frequency is unambiguously positive. The TFP increases gradually and becomes particularly large after the third year. The corresponding response to a 100 Mbps broadband shock is almost muted during the first four years, and we obtain a positive and significant response only in the fifth year. As highlighted in the introduction, this could be due to the relatively more recent deployment of fast broadband across Europe. While 30 Mbps was rolled out in most regions during the early years of our sample period, the 100 Mbps became widely available only toward the end of the period under examination. In the remainder of the paper, we will focus on the results related to 30 Mbps shocks because it is hard to detect interaction effects for the 100 Mbps estimates.

5.1 Broadband access and firms TFP polarisation

Over the last 20 years, several contributions have documented an increasing labour productivity gap between firms that operate at the technological frontier and the other firms (Andrews et al. (2015), Andrews et al. (2016), Akcigit and Ates (2021)). One popular interpretation of this fact is the decline in knowledge diffusion from frontier firms to laggards (Akcigit and Ates (2023)), which reduces laggard firms' incentives to engage in technology-enhancing investments. Berlingieri et al. (2019) document this discouragement effect for laggard firms, particularly in digital- and knowledge-intensive industries. The pace of technology diffusion has been related to the firms' absorptive capacity, i.e., the ability to internalise knowledge, research, and practices outside the firm (Griffith et al. (2004)). It might be tempting to see a link between enhanced broadband access and the speed of technology diffusion. By contrast, theoretical analyses such as Aghion et al. (2023) entirely reverse this prediction. Access to



(a) Broadband 30 Mbps: TFP growth (b) Broadband 30 Mbps: TFP level

Figure 10: Broadband 30 Mbps: TFP effects

The figure shows the cumulative impulse response functions and the associated 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (5). Values refer to a one standard deviation in Broadband shock. Panels display smooth transition functions constructed on the reported variables.

information technologies might reduce the overhead costs of high-productivity firms that can expand into new markets. These high-productivity firms are also incentivised to innovate, further boosting their productivity advantage. This discourages the innovation efforts of laggard firms. Empirical work on the widening TFP gap between frontier firms and the rest typically involves identifying a threshold productivity level that allows for splitting firms into two groups. For instance, the frontier firms group gathers the top 5% (or 10% or 25%) of firms in a given industry and year (see Andrews et al. (2015) for a discussion).[11] Given our reliance on local projection methods, we may abstract from any arbitrary grouping of firms and apply the smooth transition technique depicted in (5), where we focus on the firms' TFP growth rate.[12] Results, provided in Figure 10 are striking: high TFP growth firms further benefit from increased broadband connectivity, which occurs at a growing pace. By contrast, slow-growth firms only obtain limited initial benefits that eventually vanish. The analysis on the TFP level (panel b) broadly confirms that the more productive firms are the ones which benefit the most from broadband connectivity, but the difference with the least productive firms appears less marked than the one we obtained about firms' TFP growth.

[11] Berlingieri et al. (2019) adopt a bottom 40 per cent threshold to identify laggard firms

[12] This analysis may seem peculiar given that TFP growth is the dependent variable of our model. However, as stressed in section 4, smooth transition functions can be interpreted as a more sophisticated version of the interaction effect with a dummy separating, in our case, high and low TFP-growth firms.

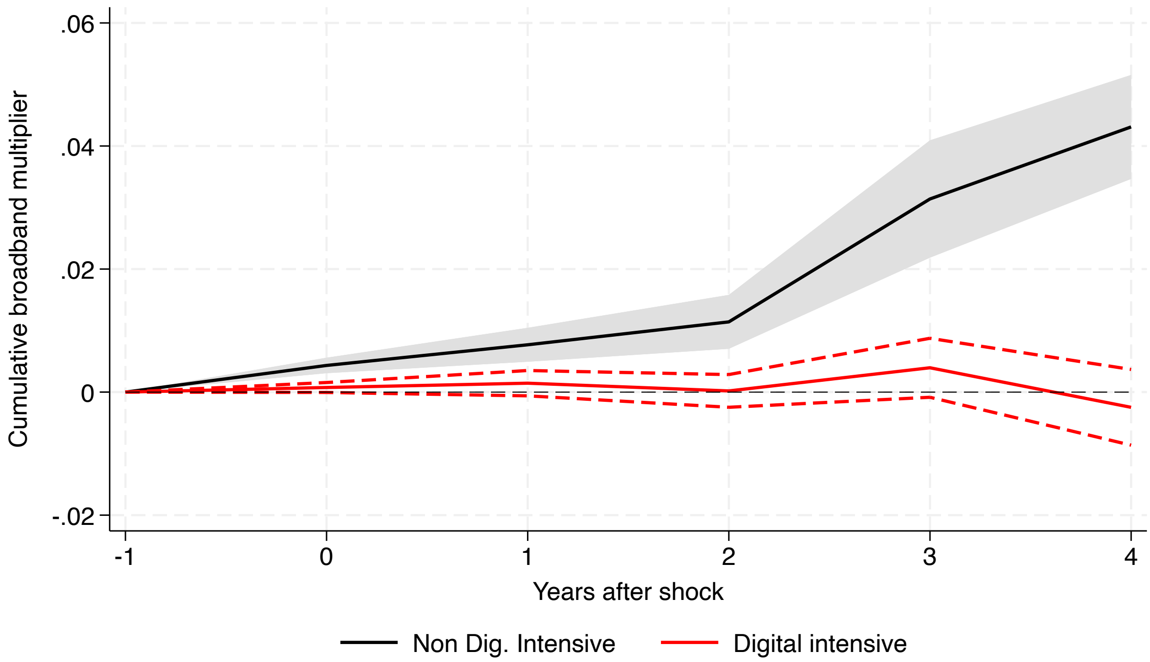


Figure 11: Broadband 30 Mbps: digitalization

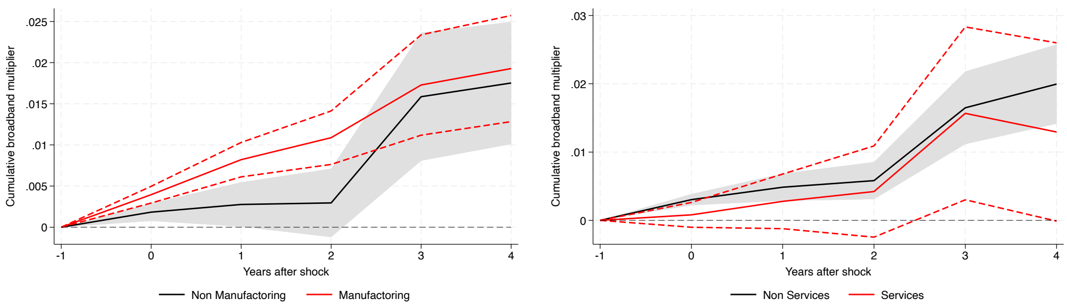
The figure shows the cumulative impulse response functions and the 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock. The figure displays the interaction effect with a dummy taking the value of 1 for firms belonging to digital intensive sectors.

5.2 Sectoral effects

We focus on two dimensions to investigate the importance of firms' sectoral specialisation. The first relates to a fundamental question concerning whether broadband availability is a technology specific to particular sectors or can be interpreted as a general-purpose technology affecting all sectors, as pointed out in Agrawal et al. (2023). In this case, a natural distinction is between firms that belong to digital-intensive sectors and firms that do not. We exploit the OECD taxonomy (see (Calvino et al., 2018)), which classifies sectors on a 1-4 level scale according to their digital intensity (low, medium-low, medium-high, high) to create a dummy variable taking a value of 1 if the sector belongs to the two highest categories and zero otherwise.[13] Figure 16 shows an unambiguously positive and strong response of firms' TFP in non-digital sectors, whereas the corresponding reaction in digital sectors is muted.

The second sectoral dimension we consider here is the traditional distinction between manufacturing and services. In Figure 16, panel (a) shows that the TFP of manufacturing firms immediately picks up after the shock, but this advantage is lost after three periods. Panel

[13]The results are similar if we focus instead on the highest category.



(a) Manufacturing (b) Services

Figure 12: Broadband 30 Mbps: Sectoral effects

The figure shows the cumulative impulse response functions and the 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock. Panels display the interaction effect with a dummy taking the value of 1 for digital sectors, manufacturing and services.

(b) shows that point estimates for the service industry are similar to those obtained for the rest of the economy. Still, the width of the confidence band suggests that the estimate for the average TFP growth in the service industry might hinge upon substantial heterogeneity at a more disaggregated level.

5.3 Does the local environment matter?

This section investigates the role of local economic and infrastructural conditions (Figure 13). One crucial distinction in assessing the effect of broadband on growth is between rural and urban areas. We employ Eurostat's classification of rural development at the NUTS3 level to construct a dummy variable that takes the value of one if the region is classified as predominantly urban and zero otherwise (panel (a)). We also consider an alternative specification, where the dummy variable takes the value of one if the region is primarily rural and zero otherwise (panel (b)).[14] Relative to the literature reviewed in the introduction de Clercq et al. (2023), our results show that firms in rural/non-rural areas benefit equally from broadband roll-out. This implies that closing the digital divide would unambiguously limit the productivity gap that penalises rural areas in the EU.[15] Note that the rural/non-rural distinction provides only a first degree of approximation to the more complex issue of the accessibility of relatively remote areas. Broadband connectivity allows for the substitution of connection means that require

[14]The methodology used by Eurostat is thoroughly explained at https://ec.europa.eu/eurostat/web/rural-development/methodology

[15]According to the EU, in 2013 the share of EU households with internet access was 9.7 percentage points higher in cities than in rural areas, and the difference was reduced to 4.4 points in 2023.

standard transport modes. To investigate this issue, we have used the ESPON accessibility index, which measures the degree of accessibility (by car/train/plane) of each NUTS3 region.[16] We have constructed a dummy variable, taking the value of 1 for the top 25% of accessible regions and interacted it with our Broadband shock. Results are reported in Panel (d). Firms in low-accessibility regions obtain significantly larger TFP gains over the first four years, but this result is partly reversed in the fifth year.

Our results show that firms in predominantly urban areas tend to get greater benefits from broadband coverage. This could be due to the well-known complementarity between internet-driven technological change and skilled labour (see Autor et al. (2003)). We also investigate whether the regional distribution of GDP per capita, which only partly overlaps with the degree of urbanisation but is also related to the concentration of skilled labour, could affect our results. We partition European regions based on their level of GDP per capita using smooth transition functions. As shown in Panel (c), the resulting cumulative TFP responses largely overlap. All in all, this suggests that cities' advantages in exploiting firms' TFP gains from internet access might also be related to urban-specific factors beyond the standard skill complementarity of broadband-induced technical change.

5.4 Firm-specific heterogeneity

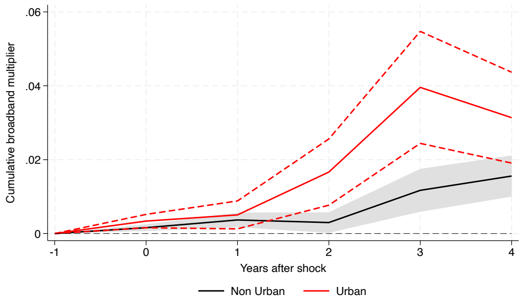
When looking at firm-specific features (Figure 14): high or low profitability, leverage, and size, measured by employment. Over time, more profitable firms benefit relatively more from broadband shocks. A relatively large size also appears to grant an advantage in exploiting broadband access. By contrast, leverage does not seem to matter.

5.5 Selected countries

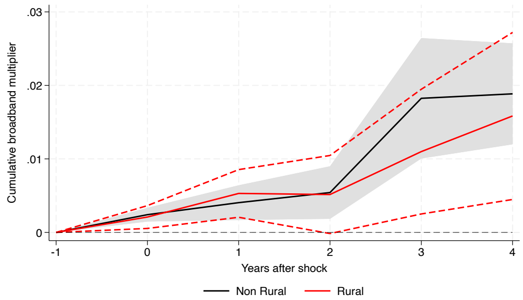
Finally, in this section we present country-specific responses. We first analyse the macro-regional dimension with a general distinction between countries between Eastern and Western European countries (Figure 15). Broadband shocks in the Eastern bloc have relatively faster effects on TFP growth. Over five years, the cumulative growth response has been comparable to that observed in the rest of the EU.

Secondly, we focus on individual countries that are the most significant contributors to

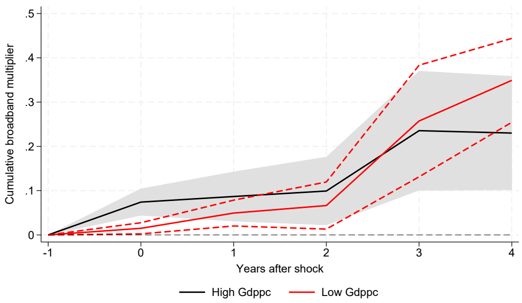
[16] More specifically, the indicator measures multimodal accessibility where for each region the population in all destination regions is weighted by the travel time to go there (considering train, car and plane). The weighted population is summed up to the indicator value for the accessibility potential of the origin region. The indicator is expressed as index related to the ESPON average. More details can be found at `https://database.espon.eu`



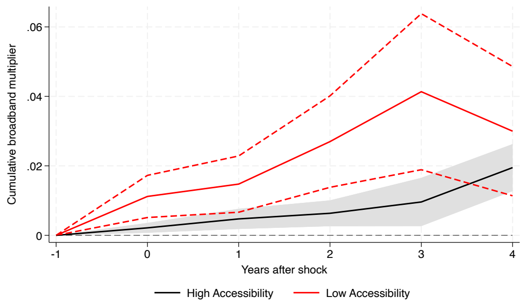
(a) Urban areas



(b) Rural areas



(c) Split by GdP per capita

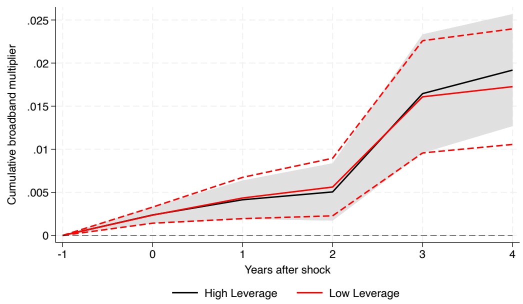


(d) Split by Accessibility

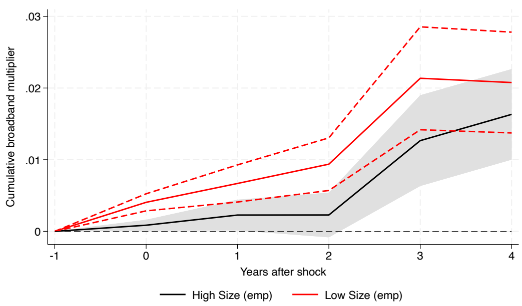
Figure 13: Broadband 30 Mbps: regional effects

The figure shows the cumulative impulse response functions and the associated 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4) (panels a) and b)) and (5) (panel c)). Values refer to a one standard deviation in Broadband shock. Panels a), b), d) display the interaction effect with a dummy taking the value 1 for urban and rural areas, and high accessibility regions, respectively. Panel c) displays smooth transition functions constructed on regions' GDP per capita.

(a) Profitability



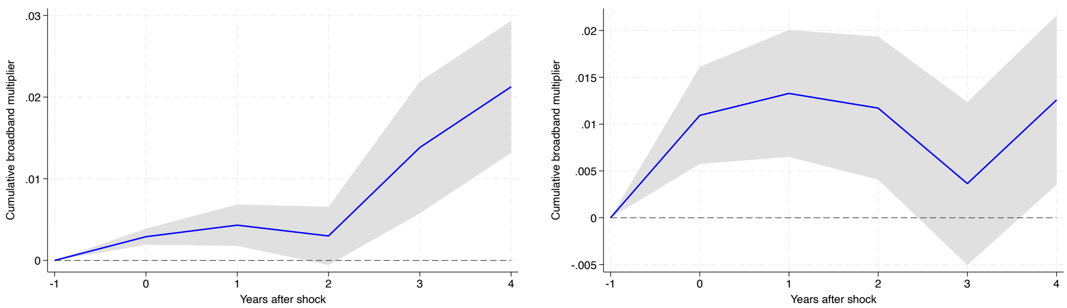
(b) Leverage



(c) Employment

Figure 14: Broadband 30 Mbps: firm-specific effects

The figure shows the cumulative impulse response functions and the associated 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (5). Values refer to a one standard deviation in Broadband shock. Panels display smooth transition functions constructed on the reported variables.



(a) 30 Mbps: Western Europe

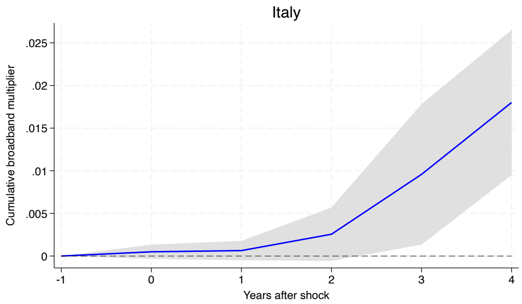
(b) 30 Mbps: Eastern Europe

Figure 15: Broadband (30 Mbps): regional effects

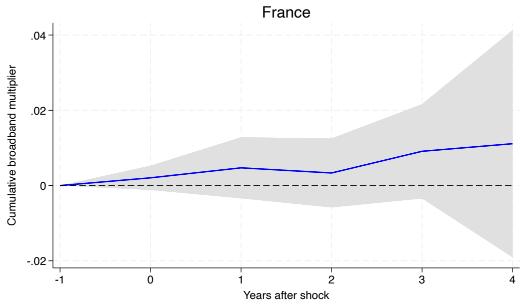
The figure shows the cumulative impulse response functions and the associated 95 percent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4).

the TFP growth dataset and belong to the Western bloc: Italy, France, Spain, Portugal, and Sweden in decreasing order of importance. Overall, with the exception of France, where the broadband effect is always insignificant, in all countries it is possible to detect a positive effect of broadband access on firms' TFP, although with different intensities and different timings.

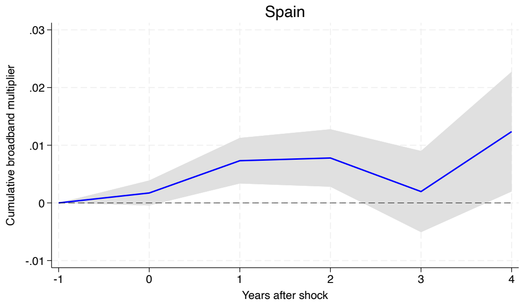
Figure 19 and 20 in the appendix reports also the country effect for the fast broadband access (100 Mbps) confirming the positive effect, albeit with a higher degree of uncertainty.



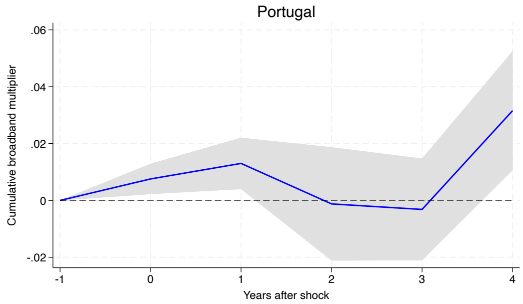
(a) 30 Mbps: Italy



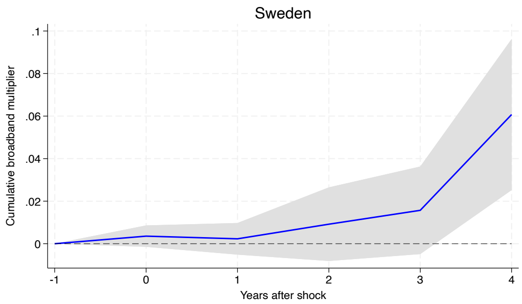
(b) 30 Mbps: France



(c) 30 Mbps: Spain



(d) 30 Mbps: Portugal



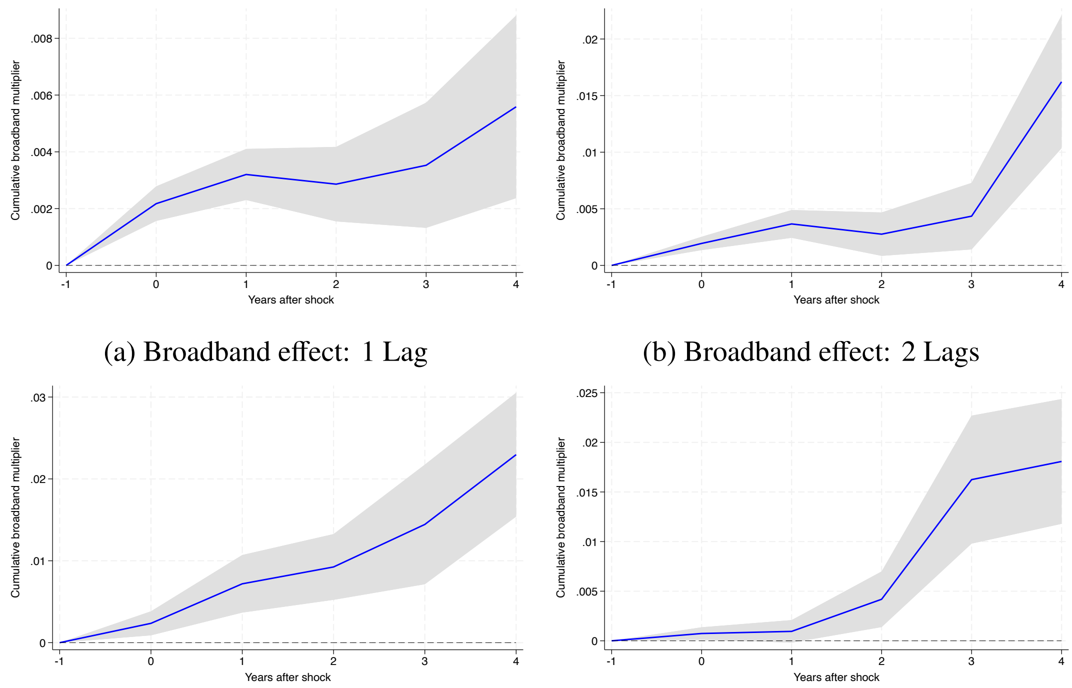
(e) 30 Mbps: Sweden

Figure 16: Broadband 30 Mbps: selected countries

The figure shows the cumulative impulse response functions and the 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock.

5.6 Robustness

We conducted a series of robustness checks to validate our results. First, we examined the impact of alternative lag structures for the broadband shock. As shown in Figure 17, specifications using one and two lags yield results that closely resemble the baseline model with three lags. Second, we excluded the period affected by the COVID-19 pandemic, which may have influenced economic performance toward the end of the sample period. As illustrated in panel (c), this exclusion does not alter the main findings. Finally, given that local projections (LP)



(a) Broadband effect: 1 Lag

(b) Broadband effect: 2 Lags

(c) Broadband effect: excluding the covid period

(d) Broadband effect: constant sample

Figure 17: Broadband 30 Mbps: robustness checks

The figure shows the cumulative impulse response functions and the associated 95 per cent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock.

are estimated over varying time horizons, longer horizons naturally result in smaller samples due to the unbalanced nature of the panel. To ensure that changes in sample composition do not drive our results, we re-estimated the model on a balanced sample of firms that survive through the most extended horizon. As shown in panel (d), the findings remain robust.

6 Conclusions

This study documents the effects of broadband coverage shocks on the TFP of firms in the European Union. The breadth of the analysis was made possible by an original empirical strategy, which extracts broadband coverage shocks from a dynamic panel estimator. This, in turn, allowed us to apply Local Projections methods to estimate the effect of broadband shocks on TFP. We estimate a strongly positive response of TFP to broadband shocks and uncover the polarising effects of these shocks: fast-growth firms and firms located in urban areas reap relatively larger TFP gains. We also detect substantial cross-country heterogeneity in firms' TFP responses, with relatively more favourable results in some southern European countries, Italy and Spain, and in the Eastern bloc of the EU. Most of these results cannot be confirmed when we focus on fast broadband connection. In any case, one should expect that fast broadband access will become a prerequisite to strengthen TFP growth as AI becomes more pervasive.

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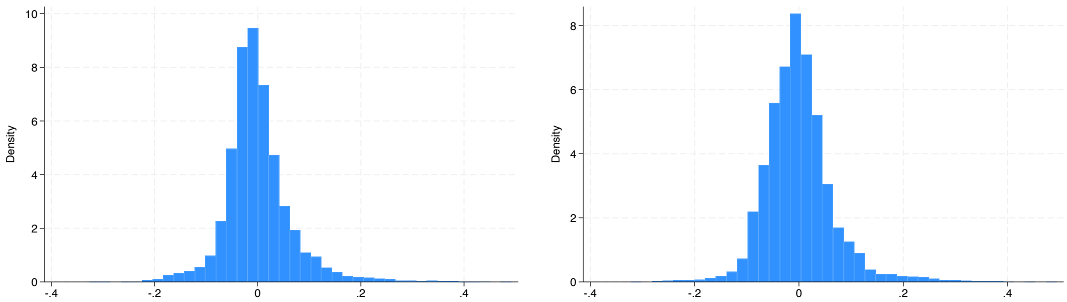
Appendix

Table 2: Descriptive statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**	Source
BB 30Mbps (%)*	0.674	0.264	0	1	10242	Point Topic
BB 100Mbps (%)*	0.520	0.301	0	1	10242	Point Topic
Leverage	0.155	0.192	0	1	6256295	Orbis
Employment (log)	2.115	1.015	0.69	9.72	6256295	Orbis
Profitability	0.14	12.3	-29757.1	7570.5	6256295	Orbis
Sales (log)	13.29	1.55	-.253	21.59	6187941	Orbis
TFP	8.443	1.783	-109.7	62.9	6256295	Orbis
TFPG	0.012	0.287	-1.5	1.5	6256295	Orbis
Digital_intensity	2.348	1.066	1	4	6256295	OECD
Accessibility*	95.38	36.79	14.7	190.83	1162	Espon
GDP pc PPS*	27.39	13.05	5.8	177.6	10242	Eurostat
Population Density*	405.11	1021.12	1.796	21640.25	10242	Eurostat

* denote variables observed at Nuts3 level



(a) BB 30 Mpbs

(b) BB 100 Mpbs

Figure 18: Distribution of Broadband shock

The figure shows the distribution of ϵ^{BB} calculated as a residual from equation (3). Table 3 reports descriptive statistics.

Table 3: Descriptive statistics BB shock

Variable	Mean	Std. Dev.	Min.	Max.	N
ϵ 30 Mbps	0	0.065	-0.326	0.718	10242
ϵ 100 Mbps	0	0.065	-0.323	0.494	10242

Table 4: Effects of broadband shock

	h=0	h=1	h=2	h=3	h=4
ϵ^{BB}	0.0024***	0.0043***	0.0054**	0.0162***	0.0181***
	(0.0004)	(0.0011)	(0.0016)	(0.0033)	(0.0032)
L.ϵ^{BB}	0.0010**	0.0018*	-0.0005	-0.0013	-0.0010
	(0.0004)	(0.0008)	(0.0008)	(0.0009)	(0.0008)
L2.ϵ^{BB}	0.0003	-0.0016*	-0.0018*	-0.0032***	-0.0040***
	(0.0004)	(0.0007)	(0.0007)	(0.0008)	(0.0007)
L3.ϵ^{BB}	-0.0014***	-0.0015*	-0.0021*	-0.0042***	0.0004
	(0.0004)	(0.0007)	(0.0008)	(0.0010)	(0.0008)
L.TFPG	-0.4812***	-0.5858***	-0.6389***	-0.6326***	-0.6472***
	(0.0029)	(0.0026)	(0.0022)	(0.0018)	(0.0022)
L2.TFPG	-0.2544***	-0.3234***	-0.3511***	-0.3373***	-0.3287***
	(0.0015)	(0.0016)	(0.0014)	(0.0018)	(0.0025)
Leverage	-0.1135***	-0.0825***	-0.0184***	0.0119*	0.0010
	(0.0051)	(0.0047)	(0.0052)	(0.0054)	(0.0051)
Size	-0.2278***	-0.0757***	-0.0305***	-0.0165***	-0.0363***
	(0.0072)	(0.0030)	(0.0023)	(0.0021)	(0.0026)
Profitability	0.0000	0.0000	-0.0000***	-0.0001*	0.0001
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Constant	0.5209***	0.1963***	0.0988***	0.0738***	0.1270***
	(0.0162)	(0.0063)	(0.0049)	(0.0048)	(0.0057)
R2	.356	.483	.606	.713	.793
N	3924235	2924245	2138532	1521257	1008904

Note: the table shows regression coefficients of the cumulative multiplier based on equation (4). Dependent variable is TFP growth. The size of the coefficient refers to the impact of one standard deviation in Broadband shock, h defines the time horizon of the IRF. All regression include firm, sector, region (NUTS3), country and time fixed effects. Robust standard errors clustered at NUTS3 level in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 5: Lag Length Selection Using Information Criteria.

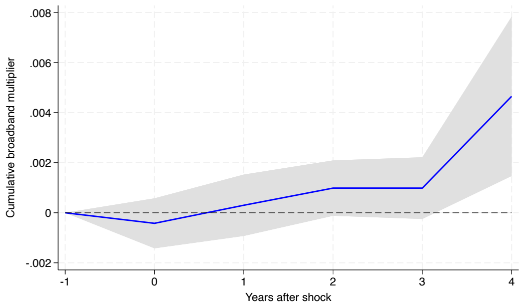
N. Lags	$k = 0$	$k = 1$	$k = 2$	$k = 3$	$k = 4$
1	-571,256.978	81,049.7683	-25,879.5913	-272,113.036	-449,965.866
2	-591,301.74	-22,468.7383	-152,786.85	-396,709.514	-528,752.563
3	-714,630.734	-241,919.36	-383,375.325	-575,458.301	-611,560.573

Note: The table shows the value of the Bayesian Information Criterion (BIC), for different lag structures and for each horizon k. The lag order that minimizes BIC for all horizons is 3.

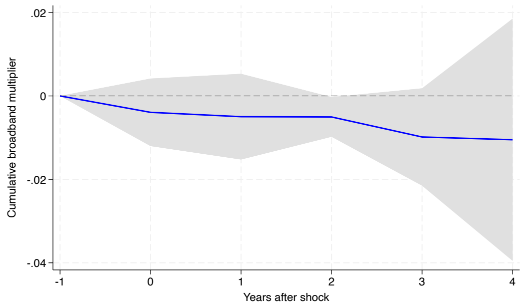
Table 6: Countries and regions

Country	Obs.	Nuts3
AT	790	32
BE	76022	41
DK	1565	11
FR	139466	96
DE	17133	396
IT	2463937	101
LU	186	1
NO	7765	11
SE	557944	21
FI	31277	18
PT	609162	23
ES	1314336	49
BG	409503	28
SK	78611	9
EE	65011	5
LV	51600	7
HU	161681	20
HR	39255	15
SI	153483	11
PL	54053	73
RO	23446	42
TOT	6256226	1010

The table reports the number of observations available at country level in the estimation sample and the number of NUTS3 regions covered.



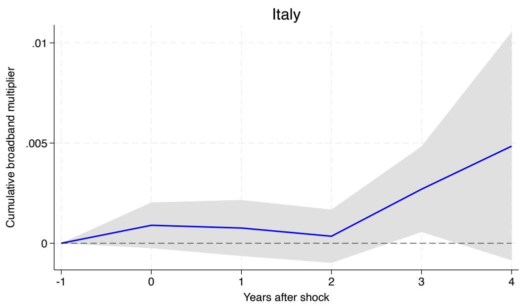
(a) 100 Mbps: Western Europe



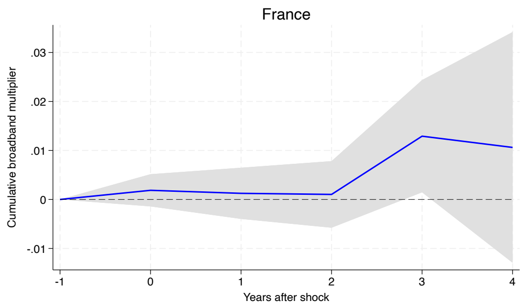
(b) 100 Mbps: Eastern Europe

Figure 19: Broadband 100 Mbps: regional effects

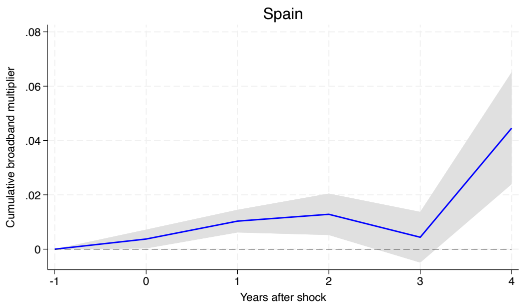
The figure shows the cumulative impulse response functions and the associated 95 percent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock.



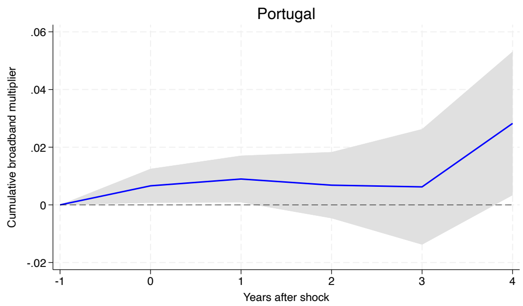
(a) 100 Mbps: Italy



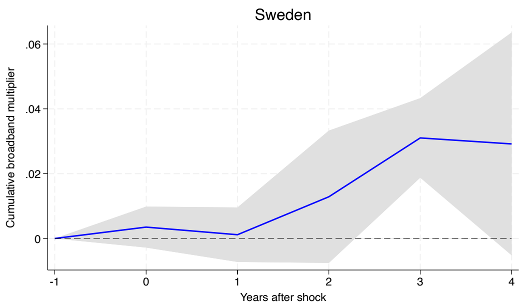
(b) 100 Mbps: France



(c) 100 Mbps: Spain



(d) 100 Mbps: Portugal



(e) 100 Mbps: Sweden

Figure 20: 100 Mbps: selected countries

The figure shows the cumulative impulse response functions and the associated 95 percent confidence bands; $t = 0$ is the year of shock. The shock is constructed using equation (3). Estimates follow equation (4). Values refer to a one standard deviation in Broadband shock.

Dataset construction

We build our dataset exploiting Orbis Historical provided by Bureau Van Dijk. We follow the approach of Kalemli-Özcan et al. (2024) and Li and Su (2022) for data cleaning. We therefore focus on non-financial corporations, accounting for variations in sector-level characteristics such as dependence on external finance and capital-skill complementarity. The data are expressed in current Euro values. We deflate the figures using a country- and sector-specific price index.

More specifically, the steps of the data preparation process we apply are the following:

- Keep only unconsolidated accounts when both consolidated and unconsolidated accounts are available:

- Keep the observation with the largest values of operating revenue when there are duplicates in firm ID and closing date; i) Filter the year from the closing date by using the current year if the month is later than June and using the previous year if the month is earlier than June; ii) for each firm-year, keep the one with the latest reporting date.

- Cancel reporting mistakes:
  i) drop observations with information on total assets, operating revenues, sales, and employment all missing;
  ii) drop observations with negative total assets, employment, sales, or tangible fixed assets;
  iii) drop observation of firms with the number of employees exceeds 1 million in any year;
  iv) Exclude observations with negative current liabilities, noncurrent liabilities, current assets, loans, creditors, other current liabilities, or long-term debt;
  v) exclude the observations if their long-term debts are higher than the liability;
  vi) Exclude Firms implying non-positive age values in any year;
  vii) Drop observations with negative values for intangible fixed assets, and drop observations with missing or zero values for tangible fixed assets;
  vii) Drop observations with missing, zero, or negative values for the wage bill;
  ix) Drop observations with negative depreciation values;

- Check for extreme values. Exclude observations that are either below the 0.1 percentile or above the 0.99 percentile of the distribution of:
  i) the ratio of fixed assets (the sum of tangible fixed assets, intangible fixed assets, and

other fixed assets) to total assets;

ii) the ratio of the sum of stocks, debtors and other current assets to total current assets;

iii) the ratio of the sum of fixed assets and current assets to total assets;

iv) the ratio of the sum of capital and other shareholder funds to total shareholder funds;

v) the ratio of the sum of long-term debt and other non-current liabilities to total non-current liabilities;

vi) the ratio of the sum of loans, creditors and other current liabilities to total current liabilities;

vii) the ratio of the sum of non-current liabilities, current liabilities and shareholder funds to total shareholder funds and liabilities;

viii) we define liabilities as the difference between total shareholders' funds and liabilities, and the shareholders' funds, then drop the observations if the value is negative or zero. Further, we obtain liabilities by adding current and noncurrent liabilities. We drop the observations if the ratio between the two definitions of liabilities is greater than 1.1 or lower than 0.9;

ix) We define net worth as the difference between total assets and liabilities, keeping the observations with the net worth equal to shareholder funds;

x) Drop observations when the ratio of tangible fixed assets to total assets is greater than one;

xi) We define the capital-labor ratio where the capital stock is the sum of tangible and intangible fixed assets. Firms reporting a capital-labor ratio in the bottom 0.1 percentile. We drop the firm-year observations with a capital-labor ratio higher than the 99.9 percentile or lower than the 0.1 percentile;

xii) Keep observations with positive shareholder funds, while the observations with the ratio of other shareholder funds to total assets in the bottom 0.1 percentile are dropped;

xiii) Drop extreme values in the bottom 0.1 or top 99.9 percentile of the distribution of two leverage indicators defined as: i) the ratio of tangible fixed assets to shareholder funds and ii) the ratio of total assets to shareholder funds; xiv) We define the value added as the difference between operating revenues and material costs, keeping the observations with a positive value added;

- To deflate the variables, we consider three measures of GDP deflators, two at a country-sector level and one at the national level. Specifically, we deflate all the financial variables of our dataset, exploiting the country-specific deflator. Then, we deflate the two measures of value added and material costs using the measure of national accounts aggregates by industry (nama_10_a64 on EUROSTAT), while investments and capital are deflated using the measure of gross capital formation by industry (nama_10_a64_p5 on EUROSTAT). We group the different sectors at a two-digit NACE category level, sharing the same deflator for different subsectors. This approach allows us to keep the highest possible level of observations. All the deflator measures are calculated as a ratio of current prices to chain-linked volumes, with 2005 as the base year.