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The Economic Impact of Broadband Access for Small Firms

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Abstract

This paper investigates the economic effects of improved broadband access at the firm level. Using a detailed micro dataset from 2002-2017 we cover almost 20 thousand small, medium and large Greek firms and test the relationship between their economic performance with the availability and use of broadband services at the postcode level. We trace the effect of increased access and speeds across industrial sectors and firm sizes. Our results highlight that increases in broadband speeds can improve the financial performance of adopting small firms (sales, profits, and labor productivity) by 2% for every speed doubling beyond basic broadband access. Unlike other output metrics, small firms do not generate increasing shares of intangible capital through this adoption process. These effects, which remain strong across a range of robustness checks, suggest that the digital transition for small firms should focus on the causes of adoption (including training and skill development) and move beyond policies aimed at increased broadband availability alone.

JEL codes: O33, L25, O47

Keywords: telecommunications, economic growth, digital access, policy

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1 Introduction

Investment in digital infrastructure enables small firms to reach a wider customer base, outside their localities. Fixed broadband access has improved significantly over the past two decades, largely relying on upgrades of existing - copper-based - networks with the installation of active equipment and the deployment of street cabinets that helped reduce average local loop lengths. While consumer preferences towards higher connection speeds have been documented (Ahlfeldt et al. (2017)), it is still unclear whether these upgrades in infrastructure have a material impact on adopting firms' economic performance.

This paper looks into the development of fixed broadband networks in Greece over the period 2002-2017 and the economic effects as a result of digital access for adopting firms. This period has been marked by a significant contraction of the economy, predominantly as a result of the global financial crisis along with other country-specific effects. In this setting, digital technologies offer an additional channel for firms to expand their economic activities and help economic recovery at the macroeconomic level. We particularly focus on the effect of broadband speed on sales, profitability, intangible capital, and productivity of adopting firms to understand the channels through which digital access may have affected them. We also look into the differences across firm sizes and industries.

To achieve this we use detailed firm microdata for a sample of 19,469 firms and connect the spatial information from these firms with their broadband service characteristics over time. Using information for the entire fixed broadband access network in the country and the location of the local distribution points (local exchanges and cabinets) we assess the maximum fixed broadband speed available to each firm at any given year. We further identify the adoption of broadband services across two spatio-temporal levels: the first runs through regional adoption at the Local Exchange (lines in use for each catchment area) and the second through firm-level communication channels (including the use of business email and website for firms). Our approach largely follows the empirical designs in Kolko (2012), Fabling and Grimes (2021) and Ahlfeldt et al. (2017). We find that, across our entire sample and both approaches, the availability of broadband speeds does not have any effect on these economic characteristics at the firm level. This is expected and reassuring, as we have no indication of whether regions or firms covered by these upgrades actually adopted these services or used them in a productive manner. To check the effects of service use, we repeat this test for adopting regions or firms and find that the increase of broadband internet speeds affects some of the key financial indications by approximately 2% every time access speeds double. Looking closer at the size effects of adopting firms we observe that adopting SMEs performance is positively correlated with increased sales, productivity and profitability but not with the share of intangible capital.

A crucial caveat in this process is to test whether there is some causal mechanism beyond the correlational nature of these findings. In the absence of a setting where an experimental design could be exploited we rely on a battery of robustness checks including a randomization of the treatment effect across our sample of firms and an event-study design. In the former, we assign broadband services to the firms that did not actually adopt which does not yield any spurious economic benefits that may have been prevalent due to other confounding causes. In the latter we explore the effects of broadband service use through an event-study approach by Callaway and Sant'Anna (2020) for the adopting firms. In this context, and aligned with the emerging literature in the field, we find strong support for the economic benefits reported in our baseline. Additionally, the dynamic treatment process highlights that the economic benefits actually appear three years after the initial adoption, which supports the need for reskilling and adaptation to the new communications services. The event-study design shows that broadband use, even without any controls for speed, is linked to our baseline findings. Overall our results from these tests are reassuring about the effects of broadband access for small firms but we find less support for medium firms. For the larger firms we find that the randomization process and the event-study designs fail to reject the null hypothesis. This correlates with the use of premium broadband services by larger corporations (using leased lines or other services), which are not linked to the availability of broadband speeds at the postcode level. This helps focus our attention onto the smaller firms in our sample which is often the focus of policy and research interest.

The rest of the paper is structured as follows: Section 2 presents a literature review on broadband infrastructure and impact in several areas including firms' performance. Section 3 presents explicitly data sources and processing used in the current research, along with the combination and merging of micro-level panel data with broadband connection characteristics, such as speed. Section 4 presents the models applied in the empirical application section and the results of the models used to explore the impact of the increase of firms' connection speed. Conclusions are drawn in Section 5 and possible future extensions in literature are discussed.

2 Background

There is long literature supporting the benefits of public infrastructure investment as a powerful driver of business investment, economic prosperity, welfare and growth (Aschauer (1989), Nadiri and Mamuneas (1991) and Gramlich (1994)).

Broadband technology is an important basic infrastructure associated with spillover effects across the economy and is often associated with lags until the full effects of broadband are realized (adoption, complementary distribution channels, technology standards). Measuring the impact of broadband has been challenging due to data availability at the firm-level and the connection with the specific service availability and use. To account for these limitations, this literature has either used macroeconomic proxies of adoption and speeds, along with firm-level samples for short periods or subnational samples. Besides, understanding the causal effects of this technology has attracted substantial interest from policymakers, given the resources that have been invested into broadband infrastructure.

During the last two decades, a number of studies have explored the influence of broadband penetration on economic outcomes. Broadly, the findings in this literature have indicated that higher broadband penetration leads to measureable economic impacts. For instance, Crandall, Lehr, and Litan (2007) show that higher broadband penetration in the US leads to increasing macroeconomic performance. Comparing US and European multinational firms Bloom et al. (2012) showed that U.S. firms used IT resources more effectively compared to the European firms; such regional differentiation may explain the reason that European productivity growth fell behind during the 2000s.

Fornefeld, Delaunay, and Elixmann (2008)) look into European countries and assess the contribution of broadband internet telecommunications and offer an evaluation of their impact on growth and productivity. Moreover, Koutroumpis (2009) uses evidence from 22 OECD countries between 2002 and 2007 to estimate the impact of broadband infrastructure on economic growth. His findings suggest that there are indeed measureable effects of broadband adoption on economic growth highlighting the persistence of network effects.

Thompson Jr and Garbacz (2011) use aggregated data from 43 countries showing that the rapid growth of broadband access could have a stronger comparative effect for low income countries (compared to their high-income peers). Czernich, Falck, Kretschmer, and Woessmann (2011) use an OECD sample and find that between 1996-2007 a 10 percentage point increase in broadband penetration raised per capita growth by 0.9 to 1.5 percentage points per year. There is further support for these findings in Tranos and Mack (2016) and Drilo et al. (2022) for the US and Croatia, along with a number of country specific studies.

Our empirical framework is motivated also by the research studies of Kongaut and Bohlin (2017) and Kongaut, Rohman, and Bohlin (2014). Their studies on OECD countries unveil that lower-income countries have benefited from increases in broadband speed, finding positive correlations with GDP. Deviating from the existing literature, they study the impact of higher connection speeds on economic outputs. We extend this idea and measure the economic outcomes at the firm-level with the interaction of adoption and speed.

The designs closest to ours are from Ahlfeldt et al. (2017), Fabling and Grimes (2021) and Kolko (2012). All these studies exploit the regional variation and the timing of upgrades to test the effects of broadband availability. We follow these approaches and devise two separate strategies, one at the region-level and one at the firm-level.

Several recent studies have used IV specifications to address the endogenous nature of broadband adoption with incomes and skills. Castaldo, Fiorini, and Maggi (2018) use dynamic panel estimators (GMM) combined with an instrumental variable (IV) two-stage regression approach in data that span from 1996 to 2010. Their findings indicate that there exists a statistically significant relationship between broadband diffusion and economic dynamics in the short, medium, and long runs. Edquist et al. (2018) use data from 135 countries for the period between 2000 and 2014. They find that, on average, a 10 percent increase of mobile broadband adoption causes a 0.8 percent increase in GDP, which is substantial as a 0.8% of world GDP accounted for approximately USD 600 billion in 2016. Ford (2018) contributes towards the same direction and quantifies broadband internet speed impact on U.S. counties economic growth.

Koutroumpis (2019) extends a structural model that accounts for the dual nature of the underlying effect of the economic impact due to increased broadband use and the effects that higher incomes have on broadband adoption. Applying the methodology in an OECD panel of countries for the period 2002 to 2016, he shows that incomes drive a significant part of adoption and the supply of broadband services. Controlling for this effect, the overall broadband demand proxied by the country level adoption per year contributes to further increases in per capita incomes.

Given our micro-economic focus, our study is closer to Chaudhuri, Raj, Sasidharan, et al. (2018). The authors use quantile regressions and compare their econometric approach with standard OLS and IV estimators and provide a broad description of the relative effect of broadband adoption over the entire firms' productivity distribution. They find evidence of positive and significant effect of broadband adoption on small firms' (informal sector enterprises) productivity, based on data for informal manufacturing sector, obtained by the Government of India's National Sample Survey Organization. Other studies have focused on the effect of higher broadband speed instead of broadband adoption (Forzati and Mattsson, 2012; Rohman and Bohlin, 2013).

DeStefano, Kneller, and Timmis (2018) use firm-specific IVs in an effort to exploit a plausibly exogenous spatial variation for broadband access in the UK. In particular, they take advantage of the fact that broadband speeds depend upon the assigned telephone exchange and the distance between each firm and the local telephone exchange. Their results show a significant positive effect of ICT hardware on firm revenues but the impact on firm productivity is less evident.

3 Data

This study relies on two main types of data: The first includes detailed firm-level information, and the second provides the available fixed broadband speeds for every location in the country.

3.1 Firm-level data

The source of our firm-level data is the ORBIS database from the data vendor Bureau van Dijk. In general, the ORBIS database contains harmonized cross-country firm-level data to explore the impact of various public policies to cross-country differences in firms' productivity, innovation and profitability. For the current research, data regarding Greek firms is utilized, covering the time period 2002-2017. Our sample includes 33,937 firms. These are further broken down into size categories based on the number of employees as explained in Bureau van Dijk user guide.[1]. Very large-sized companies employ at least 1,000 workers, large companies employ at least 150 and medium-sized companies have a minimum of 15 employees. All other firms that fall outside these categories are marked as small. The categories shares as of 2005 are presented below in Table 1

Before the analysis we followed the Kalemli-Ozcan et al. (2015) instructions to create a nationally representative sample. This process is echoed in the alignment of our firm-size distribution with national statistics in Greece where SMEs represent approximately the

[1] https://www.wu.ac.at/fileadmin/wu/s/library/databases_info_image/ugorbisneo.pdf

Company Size Categories	
Small	66.36%
Medium	30.46%
Large	2.91%
Very Large	0.28%

Table 1: Firms by category as of 2005. The largest category is Small-sized firms with a 66.36%. Medium-sized category is following with a large percentage approximately equal to 30.46%. Large and Very Large-sized firms stand for the 3.19%.

96.8% of all firms, while Large and Very Large-sized companies represent for the remaining 3.23%. Further, throughout the time period the panel data covers, no change in enterprises' size classification is observed.

The location of each firm is important in our work and for this we recover the longitudinal data based on the available addresses [2]. Figure 1 shows the location of every business in our sample.

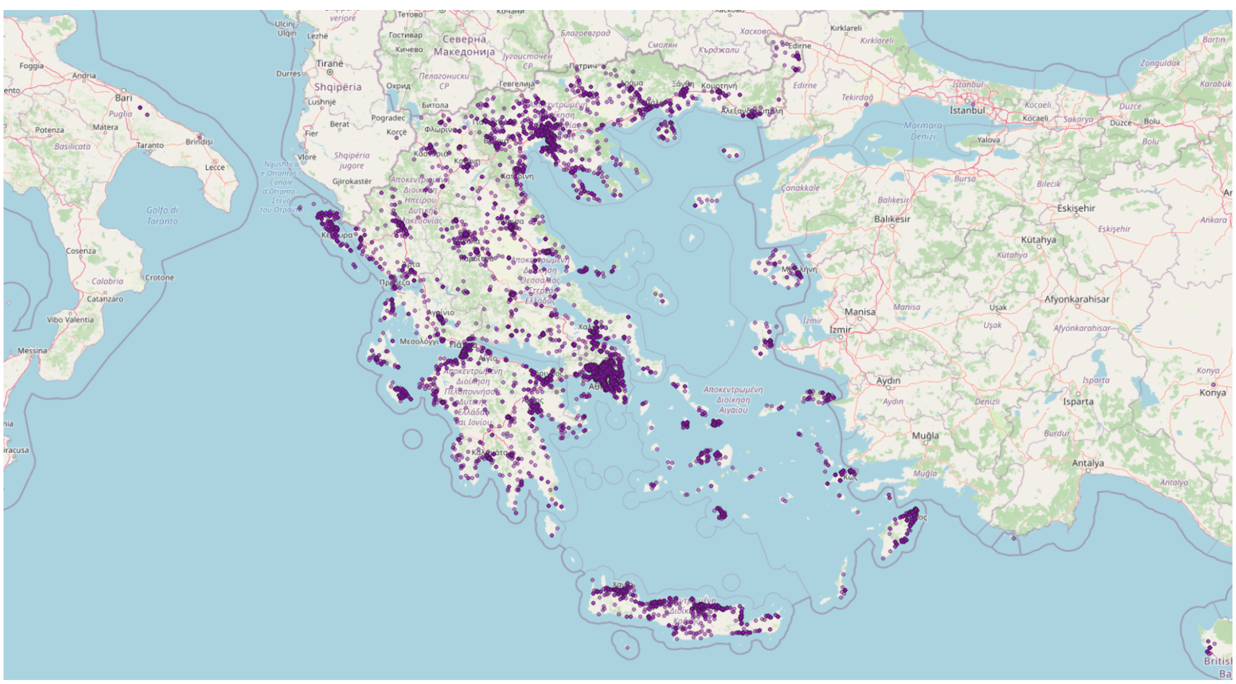


Figure 1: Firms exact location based on ORBIS dataset. The purple dots indicate the firms' exact location of all company categories. Clearly, most of the companies are located in large cities such Athens, Thessaloniki, Patra and Irakleio in Crete island.

[2]We use the "pygeocoder" package in Python, and interface for Google Geocoding API V3 that can easily be used to geocode, reverse geocode, validate and format addresses. https://pypi.org/project/pygeocoder/

3.2 Broadband Data

The key input in our broadband dataset is to provide a reliable estimate of the maximum available speed for each firm location and year. This information is not readily available from any resource that we came across and for this we construct this information from secondary data sources.

There are two key parameters that define the maximum speed at each location: the first is the date (year) that every firm was covered by a new broadband technology (ADSL or VDSL) and the second is the distance of the copper line the connects the firm's address to the closest distribution point. For the ADSL technologies this distribution point is called a Local Exchange whereas for VDSL it is called a Cabinet. Both the locations and the distances for the older generation of broadband that started to emerge in the mid-2000s (ADSL) are not the same for as in the VDSL case, an crucial paremeter that affects final speeds and has been incorrectly used in recent studies looking into these questions for the UK (DeStefano et al., 2018; Geraci et al., 2022). The reason for that is that the deployment of VDSL relies on the reduction of the long copper distances of ADSL distribution for the "last-mile" and hence drastically increases those speeds by bringing the new distribution points (cabinets) much closer to the final consumers. VDSL technologies started to appear in 2009 in the UK and in 2011 in Greece, reaching more than 80% of the population within 3 years. As a result these are crucial for the estimates of maximum available speeds. To achieve this we need to know the type of technology that is available in the Local Exchange (LE) or cabinet where firms are connected to and the distance that the copper cables have to cover from that distribution point up to the firm's address. We start from the locations and technologies of the fixed broadband distribution points.

We first collected the data for the locations of the distribution points and their activation dates. We compile this information from a dataset showing the coordinates of Local Exchanges (ADSL) and cabinets (VDSL) which covers the entire country[3]. This collection

[3]https://kafao.site/adsl/

has been crowdsourced by users who voluntarily add and edit all ADSL, VDSL and FTTH[4] LEs and street cabinets.

To compare the validity of this dataset we use the information published by the national regulator (EETT)[5]. Figure 9 in Appendix section A.2, represents the location of ADSL street cabinets in Greece in 2020. The exact number of the cabinets is 38,321, mostly located in densely populated cities. In addition, for the same cabinets, the coverage area information is available, giving us the opportunity to link each firm's address uniquely with the correspondent street cabinet. Due to imperfect matching and missing data for some cabinets we end up with 27,378 cabinets (71% of the total), which allows us to compute each firm's distance.

At this stage we have achieved two goals: we have identified the locations of fixed broadband distribution centers (Local Exchanges or cabinets) and estimated their distance from every firm. The last part we are after relates to the actual speeds achieved at each location and year. For this we collect historical speed data curated and performed by the Measurement Lab (M-Lab)[6], an open source project with contributors from public institutions and organizations, as well as private sector companies. Measurement connection tests are accessible via the Google Cloud Platform (BigQuery) allowing users to run queries with information about historical connection speed test data from all over the world at the postcode level. We collected all available speed tests for every region, using the Network Diagnostic Tool (NDT-web-100 protocol)[7] which covers the period from 2005 to 2019 for the country.

Armed with this information we proceed to the final part of our data collection which relates to the activation dates of each distribution point. The first round of LE upgrades was linked to ADSL technologies and the copper lines running from the LE to each firm location. From 2010 onwards VDSL technologies (also referred as Fiber to the Cabinet in

[4]Fiber To The Home cabinets

[5]https://www.eett.gr/opencms/export/sites/default/admin/downloads/Consultations/PCCOPPERMIGRATION2021.pdf

[6]https://www.measurementlab.net/data/

[7]https://www.measurementlab.net/tests/ndt/web100/

other countries) gradually started to emerge offering higher speeds (up to 50Mbps) to their end users and shortening the "last-mile" distance lengths by the construction of cabinets within the LE catchment areas. To capture this change in the distances we use a separate source of information regarding the upgrade dates of LEs (both the ADSL and VDSL) and the cabinets (VDSL only). Our source for this information is the Greek National Regulator (EETT)[8] and the ADSLgr forum[9], that contains the dates of LE and cabinet activations by year and LE/cabinet and the number of available and active lines per LE/cabinet. This dataset allows us to have the correct distance from each LE and cabinet by year, following the activation dates, which will be used to construct the maximum speed available in each location. This also allows us to measure the level of adoption at the LE level by constructing a variable that proxies the use of communications' services at the LE/cabinet level.

3.3 Matching

Once our firm-level and speed information data are constructed we merge them based on the address and year for each firm. Each LE/ cabinet in our dataset is matched with a list of postcodes showing their exact catchment area. For the firms whose address does not match any of the available locations in the coverage data, we join them with the respective street cabinet using a minimum distance criterion (less than 5km from the LE, 3km for the cabinet). The firm-level data are matched with the activation dates of each LE/cabinet.

The last part in this process is to identify the subscription status and usage patterns for our sample of firms. Given that there are no public records for firm-level adoption we proceed with the construction of two indirect proxies of broadband use. In particular we first exploit the adoption patterns at the LE/cabinet level over time to assess whether an area demands and uses more these services. The use of this adoption metric rests on the assumption that SME and household adoption are highly correlated within small catchment areas like Local Exchanges and cabinets. In our second approach we exploit

[8]The authors wish to thank the President of EETT, Prof. Konstantinos Masselos for the provision of data at the Local Exchange level for this study

[9]URL of forum's thread ADSL enablement data is the following: https://bit.ly/2ZCSdgb

the variables available in the firm-level dataset which show whether a firm has a digital footprint, which for the period we study and the scope of firms (small and medium) can be proxied by the combined use of a business email address and website. This joint digital use is sourced from Orbis annual records at the firm level. For business digital presence we mark only the firms that have been registered with a standard network provider (such as @otenet.gr or @"firm-name".gr) and own or operates a business website. The existence of a business e-mail with the use of a network provider in its domain (like @otenet.gr) is a strong signal of broadband adoption as OTE is the local incumbent operator providing access services and there are no cases of email only provision for this matter. The existence of a website is a less transparent way to infer this information as business websites may be hosted elsewhere without actual broadband adoption by first, even though this might not be the norm. Using the combination of these "treatments" as our second proxies for adoption we proceed to the next steps in our analysis. In this process we do not account for internet access by firms that is not associated with either e-mail or website use.

For our adoption-based regional proxy, we mark the activated areas and limit the effect of each upgrade by 3km from the LE for ADSL and by 1km from the cabinet for VDSL based on the standard speed dissipation effects of the technical literature. For the firm-specific speed approach which requires a firm-specific speed function instead of a binary metric of the first approach, we rely on the same literature which shows that download speeds for ADSL and VDSL technologies are largely driven by the distance to the respective distribution point. As the speed test data do not cover all firms in the sample we construct a speed variable based on the information available. In particular, for each location and year, we construct random samples from the existing speed tests, and run a linear regression that links speeds with distance from the LE/cabinet :

$$log(downloadSpeed_{it}) = \beta_0 + \beta_1 dist_{it} + \beta_2 dist_{it}^2 + \beta_3 dist_{it}^3 + \beta_4 dist_{it}^4 \quad (1)$$

where i represents the firm and t the year each time is examined. Repeating the process for 3000 times for each year, the average of each coefficient is selected to construct the implied download speed for all missing data. This approach resembles the speed estimation in Ahlfeldt et al. (2017) and the results of this process are illustrated in Figure 2.

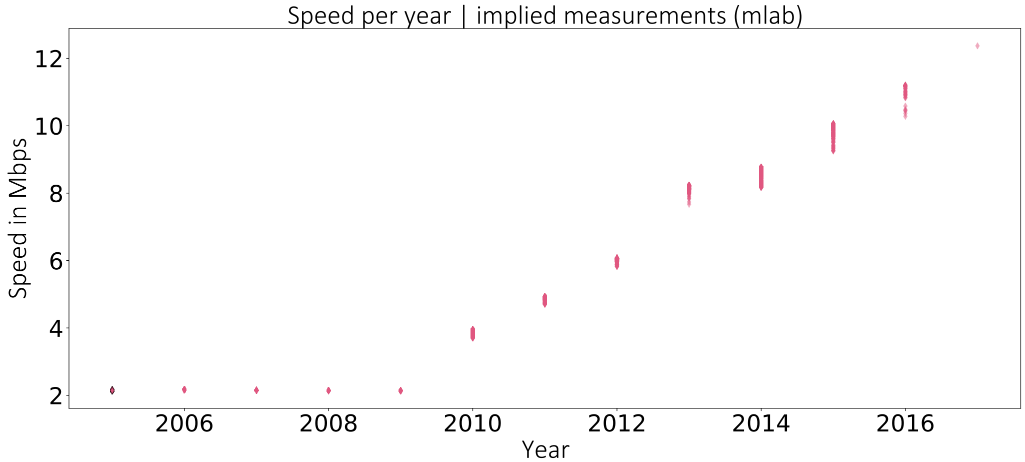


Figure 2: The implied download speed for each year after missing value imputation based on simulated linear regression

In order to check the validity of this approach at the aggregate level, we compare the outcomes from this imputation process to other available speed data. In particular we use a different set of speed tests provided by the Quarterly Internet Connectivity Reports of Akamai Technologies[10]. The average download speed (Mbps) as reported annually in the reports for Greece in Figure 3 is in line with the implied speed as per the current study. The reason for a larger speed estimate obtained in our sample is due to the fact that we assess the maximum available speed in each location rather than the actual subscribing speed. This means that firms in a given location may seek broadband access that is lower compared to the available speeds in their locations (for example subscribe to ADSL when VDSL is already available).

With these speed predictions, we now have a set of speeds for each firm for the entire period we study through their distance from the Local Exchange/cabinet. Firms that have partial information about their location or are not assigned to any street cabinet are dropped. Our final dataset contains 19,469 firms and are shown along with the assigned

[10]https://www.akamai.com/us/en/resources/our-thinking/state-of-the-internet-report/global-state-of-the-internet-connectivity-reports.jsp

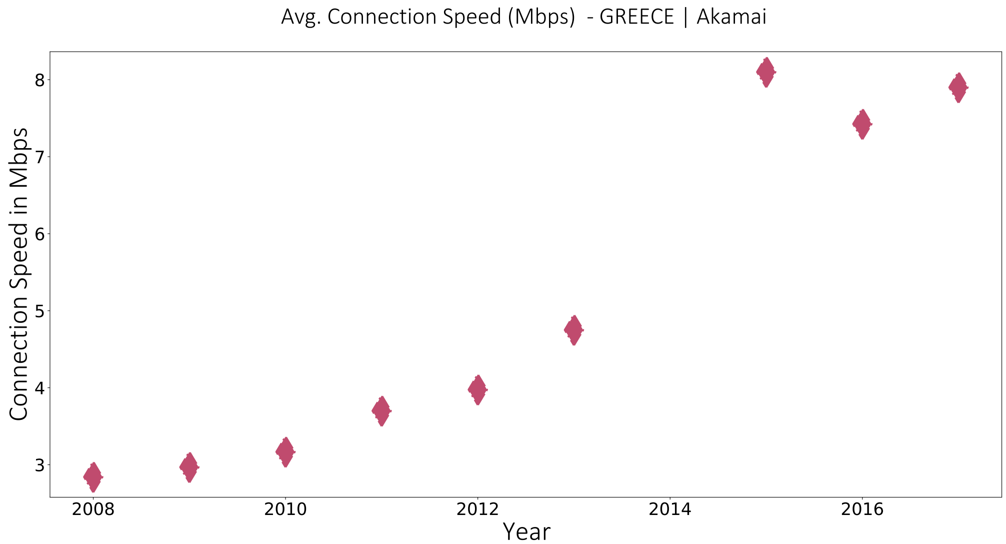


Figure 3: Average reported download speed in Mbps for Greece. 2014 report of Akamai Technologies does not report data for Greece.

street cabinets in Figure 8 in the Appendix. The map visualizes the firms in darker purple dots that are linked with the corresponding street cabinet in triangle-shaped pink points based on the coverage area data combined with the minimum distance criterion. In Appendix A.2 the same map is available zoomed over the dense Attica region (Figure 6) and the center of Athens (Figure 7).

In our firm-level panel dataset, we bring together for each firm the Technical Center name from the DSLAM data, and the activation date of the ADSL network. We limit the time period from year 2003 to 2017 and present the summary statistics for gross profits and turnover indices per year in Tables 8 and 9 in section A.1 of the Appendix. According to both means and medians, gross profits and turnover have steadily increased from 2005 onwards, with an expected drop after 2009 in the aftermath of the financial crisis. Similar findings for the other economic variables are presented in Appendix A.1. Table 7 depicts summary statistics of the gross profits regarding firms located in dense Attica and the rest of Greek region.

4 Empirical Application

4.1 Empirical Specification

The main hypothesis used in our empirical setting is that access and use of communications services will have a material impact on firms financial performance. To test this, we use a simple model in the following form:

$$log\ Y_{it} = \beta_i X_{it} + \alpha_{inc} + \gamma_{trc} + \epsilon_{it} \tag{2}$$

where Y_{it} is the vector of the dependent variable which will account for various financial indices of firm's i performance such as turnover, sales, gross profits, labor productivity and the share of intangible capital at time t. The independent variable X_{it} includes various categorical variables such as information about the network e.g. activation information of firm's i at the specific time period t (the Activation Boundary variable) or the available speed at year t and location of firm i (the Available Speed variable). Firm-level effects $\alpha_i nc$ represent unobserved characteristics of each firm i in a company classification code n and company size cluster (small, medium) c that affect its performance in a fixed manner over time and similarly $\gamma_t rc$ indicate the year effects for all observations in region r and company cluster c. Finally, ϵ_{it} represents the random error and is assumed that is normally distributed.

Additionally, we proceed with an estimation of the effects of the internet speed on several economic indices, using interactions with variables that indicate whether firm i at the specific time period t, resides in an area with high or low adoption of internet access or owns an email address and a website. In this context, Equation 2 becomes:

$$log\ Y_{it} = \beta_i X_{it} U_{it} + \alpha_i + \gamma_t + \epsilon_{it} \tag{3}$$

where X_{it} represents the existence of an upgrade at the LE/cabinet or the available speed at year t and location of firm i. The type of adoption is a continuous variable for the regional approach (adoption U_{irt}) and binary variable for email or website use encoded in the U_{it} variable.

4.2 Results

4.2.1 Baseline Results

We start with the first approach that looks into the spatial effects of activation and adoption per LE and then proceed to the speed availability results for all firms. Table 2 shows the estimation results of the basic OLS regression of the logarithm of download speed on the key economic performance variables.

As shown in the first row of Table 2 the effect of a new upgrade in the catchment area with ADSL or VDSL on the economic variables we test is not significant. In Table 2 we use a fairly restrictive set of fixed effects which control for firm-sector-classification specific and year-region-classification specific shocks. The reason for this set of controls is that firms of different sizes, sectors and regions may share common characteristics beyond the effects that year and firm effects can capture. We also present the results without fixed effects, with firm and year effects only, with firm-classification and year-classification only and the baseline ones in the Appendix (Tables 11 - 15). We do observe a negative link between Gross Profits and this might be linked to the intensity of competition in a region when communication networks are deployed. However we do not have a direct mechanism to explain this finding.

We then interact the adoption of high-speed lines in the Local Exchange or cabinet with the activation variable. This is an indirect proxy of the intensity of use at the regional level for all firms. We also observe that there is no significant effect across firms in this setting. Next we introduce a company size interaction and show the activation and adoption effect for small firms. We find that across all economic variables the effects are significant and most of them are positively linked to activation and adoption of new communications networks. Sales, operational revenues, profits and labor productivity all appear to increase with the adoption of high-speed communications. However, intangible share is negatively linked to this change, albeit very small, suggesting that small firms in these areas did marginally worse that small firms in areas with lower adoption. To give a context about this economic variable, more than 60% of small firms report no intangible capital and up to 90% of them report less than 2% share of intangible capital. This effect might actually suggest that firms with a higher intangible share are located in regions where adoption is low which - even if true - is eight to ten times smaller compared to the effects we find for all other economic variables.

When we repeat this exercise for medium firms we observe that none of the economic variables are linked to adoption or activation of new broadband technologies. The only marginally significant result we find is related to intangible shares for medium sized firms which is also very small to have any meaningful effect.

We next move to the second approach and use firm-specific speeds to infer the link between adoption of digital communications and firm outcomes. We start with a simple regression of the available speeds per firm and year in Table 3. The link with speed availability is both insignificant and practically zero for all variables. This is largely expected as the upgrade of an area per se, does not translate into tangible economic outcomes on its own. We then use a proxy of digital adoption by firms (the use of a business website and email) and interact this with the speed availability. While operational revenues, productivity and sales are not affected by this adoption, the profitability of firms and intangible shares are. In particular we find a strong positive effect on gross profits for adopting firms in high-speed areas and a rather small negative effect on intangible shares (which again, in the case of small firms is not easy to interpret). Next we look into small and medium firms separately. Starting from small firms and their interaction with Digital use and available speed we find that across most economic variables the main effects of the first approach still hold. Operational revenues, sales and productivity are all positive and significant while intangible shares are negative and significant as before. This second approach at the firm level provides some reassurance about the first region-specific effects for the majority of the economic outcomes we are after. The magnitude of the coefficients in this second approach is three times larger compared to the first, which is also expected as in the first approach all small firms in a high adoption region are included and in the second only those that have some form of digital use. However, as the region-specific "treatment" is more robust in terms of the input data used we consider the first approach results as our baseline and the second as a reassuring counterpart with a separate set of data. We also present the results for the second approach without fixed effects, with firm and year effects only, with firm-classification and year-classification only and the baseline ones in the Appendix (Tables 16 - 19).

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**Turnover**	**Sales**	**Gross Profits**	**Labor Productivity**	**Intangible Share**
Activation Boundary (AB) = 1	-0.029	-0.028	-0.061**	-0.019	-0.004
	(0.019)	(0.019)	(0.026)	(0.024)	(0.003)
Observations	88,635	88,648	87,428	67,894	90,638
R-squared	0.886	0.886	0.798	0.799	0.704
AB X Adoption	0.043	0.045	0.063	0.003	-0.001
	(0.028)	(0.028)	(0.039)	(0.035)	(0.004)
Observations	87,478	87,491	86,298	66,957	89,481
R-squared	0.886	0.886	0.798	0.799	0.703
AB X Adoption X small	0.021**	0.020**	0.030**	0.024*	-0.003**
	(0.009)	(0.009)	(0.013)	(0.012)	(0.001)
Observations	87,478	87,491	86,298	66,957	89,481
R-squared	0.886	0.886	0.798	0.799	0.703
AB X Adoption X medium	-0.009	-0.010	-0.017	-0.011	0.002*
	(0.009)	(0.009)	(0.012)	(0.011)	(0.001)
Observations	87,478	87,491	86,298	66,957	89,481
R-squared	0.886	0.886	0.798	0.799	0.703
Firm X Nace_code X Comp_Cat FE	YES	YES	YES	YES	YES
Year X Region X Comp_Cat FE	YES	YES	YES	YES	YES

Table 2: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All dependent and the adoption variable are are in logarithms. Activation boundary, small and medium variables are binaries. Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

VARIABLES	(1) Turnover	(2) Sales	(3) Gross Profits	(4) Labor Productivity	(5) Intangible Share
Speed (available in log Mbps)	0.002	0.002	-0.004	-0.001	0.000
	(0.005)	(0.005)	(0.006)	(0.005)	(0.001)
Observations	88,635	88,648	87,428	67,894	90,638
R-squared	0.886	0.886	0.798	0.799	0.704
Digital use X Speed	0.015	0.015	0.054***	0.019	-0.008***
	(0.009)	(0.009)	(0.012)	(0.013)	(0.001)
Observations	88,635	88,648	87,428	67,894	90,638
R-squared	0.886	0.886	0.798	0.799	0.704
Digital use X Speed X small	0.084***	0.084***	-0.013	0.072***	-0.010***
	(0.018)	(0.018)	(0.023)	(0.025)	(0.002)
Observations	88,635	88,648	87,428	67,894	90,638
R-squared	0.886	0.886	0.798	0.799	0.704
Digital use X Speed X medium	-0.059***	-0.059***	0.073***	-0.069***	0.007***
	(0.018)	(0.018)	(0.023)	(0.025)	(0.002)
Observations	88,635	88,648	87,428	67,894	90,638
R-squared	0.886	0.886	0.798	0.799	0.704
Firm X Nace_code X Comp_Cat FE	YES	YES	YES	YES	YES
Year X Region X Comp_Cat FE	YES	YES	YES	YES	YES

Table 3: OLS estimates of broadband speed availability and its interaction with firm-size. All dependent and the speed variable in logarithms. Digital use, small and medium variables are binaries. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

4.2.2 Event study framework

As a further test to the original TWFA links observed between broadband speed and economic outcomes we use an event study framework with multiple periods and dynamic treatment effects. This literature which started with the original approach by Abadie (2005) has recently been expanded by several methods that help control for the limitations of the TWFE estimators in staggered Difference in Differences designs (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2020). In this paper we use the estimators from the Callaway and Sant'Anna (2020) work and the DiD R package [11]. This Difference-in-Differences (DiD) estimator allows for variation in the treatment timing as well as the heterogeneity of the treatment effect. This appears to capture well the situation in the current setting, since the effect of participating in the treatment (digital use through a website and business email address) can vary across firms and exhibit potentially complex dynamics, selection into treatment, or time effects. Importantly, in this section we deviate from our baseline specification where we interact the treatment with the available speeds and instead use the treatment (website or email) only as a predictor of firm performance. Since we depart from our original design - which would not be possible to integrate in a binary treatment - we first present the results of our baseline without any speed controls in Table 4. The results for the digital use treatment and firm sizes appear to behave similarly to our baseline but the coefficients are now higher due to the omission of speed from the regressions.

We now turn to the results from the event-study design. Tables 5 and 11 include these estimates for small and medium-sized firms. First, we focus on the average treatment effect (ATT) which show a very similar pattern compared to the OLS estimators. For small firms turnover, sales, profits and labor productivity are significantly linked to broadband service use (either email or website) whereas the intangible share remains insignificant. The medium sized firms appear to be affected only in their intangible shares for one type of treatment, suggesting that the estimates in our baseline are not sufficiently supported in this design. The dynamic nature of the treatment in small firms is shown after 3 years of

[11] https://github.com/bcallaway11/did

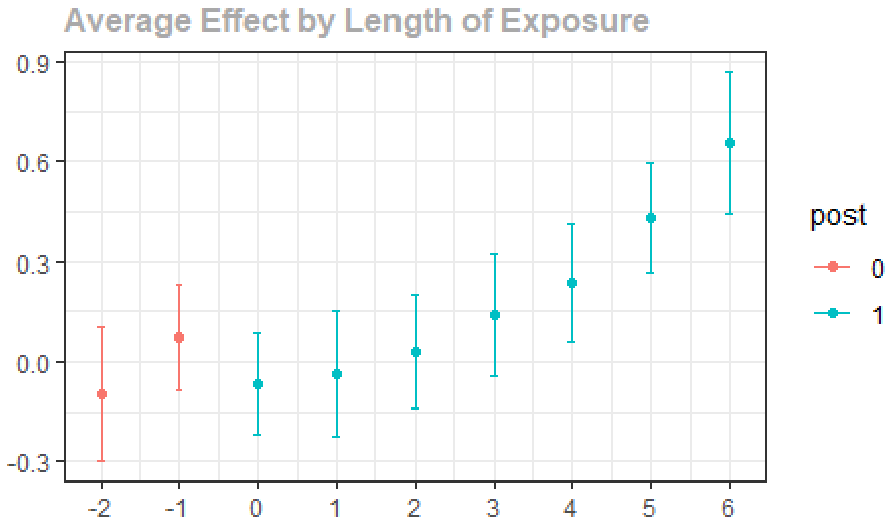
	log(Turnover)	log(Sales)	log(Gross Profits)	log(Labor Productivity)	log(Intangible Share)
I. Small-sized firms					
Email use					
email	0.9722***	0.8089***	0.8667***	0.7736***	0.1770*
	(0.0255)	(0.0221)	(0.0260)	(0.0287)	(0.0867)
Website use					
website	0.3338***	0.2924***	0.3716***	0.2061***	0.5043***
	(0.0172)	(0.0146)	(0.0173)	(0.0170)	(0.0568)
Observations	30,148	29,529	29,263	23,500	29,103
II. Medium-sized firms					
Email use					
email	0.5927***	0.5020***	0.5084***	0.3076***	0.4536***
	(0.0250)	(0.0230)	(0.0268)	(0.0259)	(0.1038)
Website use					
website	0.2355***	0.2239***	0.3491***	0.0169	0.9910***
	(0.0128)	(0.0114)	(0.0134)	(0.0116)	(0.0528)
Observations	50,191	49,485	48,831	44,440	49,973
Year Effects	✓	✓	✓	✓	✓
Firm Effects	✓	✓	✓	✓	✓

Table 4: OLS results for small and medium-sized firms. The log effects of all four economic variables are estimated based on a fixed effects OLS specification controlling for year and industry effects. Inference: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

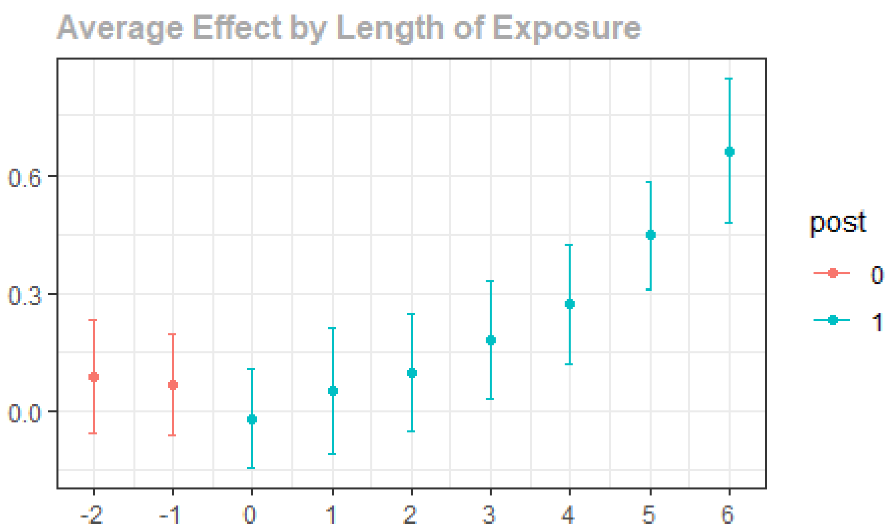
adoption into the services where sales and profits first appear to have a significant increase. After 4 years of adoption the effects are evident and strongly significant across all financial outcomes. For medium sized firms, the intangible share has a similar behavior after 3 years of adoption into the services. Figures 4 and 10 shows the pre- and post-treatment effects in red and blue dots respectively, for small and medium firms revenues and sales.

	Turnover	Sales	Gross Profits	Labor Productivity	Intangible Share
DiD in Small sized					
I. Email use					
Overall group-time average treatment effect (ATT):					
email	0.1993***	0.2401***	0.1997***	0.4638***	-0.192
	(0.0478)	(0.0438)	(0.0454)	(0.1471)	(0.1598)
Dynamic Effects:					
event time					
-2	-0.0967	0.0865	-0.1126	-0.0363	-0.0910
	(0.0744)	(0.0485)	(0.0651)	(0.0574)	(0.1832)
-1	0.0720	0.0661	0.0365	-0.0410	0.0011
	(0.603)	(0.0489)	(0.0561)	(0.0604)	(0.1828)
0	-0.0666	-0.0216	-0.0616	0.0548	0.0826
	(0.550)	(0.0463)	(0.0515)	(0.0591)	(0.1929)
1	-0.0346	0.0512	-0.0400	0.0505	-0.1375
	(0.0648)	(0.0596)	(0.0657)	(0.0699)	(0.2027)
2	0.0322	0.0965	0.0213	0.0492	-0.0937
	(0.0629)	(0.0544)	(0.0591)	(0.0629)	(0.2149)
3	0.1390	0.1775*	0.1683*	0.1861*	-0.1302
	(0.0624)	(0.0546)	(0.0548)	(0.0640)	(0.2103)
4	0.2367**	0.2699***	0.2600**	0.3786***	-0.3990
	(0.0601)	(0.565)	(0.0578)	(0.0650)	(0.2075)
5	0.4296***	0.4454***	0.4082***	0.7410***	-0.2687
	(0.0573)	(0.0555)	(0.0546)	(0.0702)	(0.1982)
6	0.6591***	0.6615***	0.6420***	1.2188***	-0.3976
	(0.0694)	(0.0688)	(0.0733)	(0.0784)	(0.2272)
II. Website use					
Overall group-time average treatment effect (ATT):					
website	0.1352**	0.2401***	0.1525***	0.2108***	-0.0855
	(0.0422)	(0.0454)	(0.0418)	(0.0437)	(0.1673)
Dynamic Effects:					
event time					
-2	-0.0928	0.0865	-0.0861	-0.0541	-0.0446
	(0.0682)	(0.0515)	(0.0573)	(0.0581)	(0.1982)
-1	0.0835	0.0661	0.0466	-0.0464	0.0613
	(0.0531)	(0.0501)	(0.0557)	(0.0531)	(0.2000)
0	-0.0953	-0.0216	-0.0768	0.0243	0.1118
	(0.0515)	(0.0478)	(0.0503)	(0.0506)	(0.2042)
1	-0.0366	0.0512	-0.0303	0.0162	-0.0051
	(0.0583)	(0.0524)	(0.0548)	(0.0557)	(0.2141)
2	0.0326	0.0965	0.0267	0.0166	0.0400
	(0.0521)	(0.0558)	(0.0519)	(0.0590)	(0.2005)
3	0.0765	0.1775*	0.1344*	0.0441	0.0076
	(0.0517)	(0.0583)	(0.0503)	(0.0548)	(0.2084)
4	0.1996**	0.2699***	0.2297**	0.2134**	-0.2170
	(0.0548)	(0.0571)	(0.0518)	(0.0535)	(0.2103)
5	0.3485***	0.4454***	0.3556***	0.4672***	-0.2353
	(0.0578)	(0.0553)	(0.0547)	(0.0567)	(0.2108)
6	0.4207***	0.6615***	0.4284***	0.6940***	-0.3003
	(0.0645)	(0.0644)	(0.0616)	(0.0663)	(0.2180)

Table 5: Aggregated group-time average treatment effects of email and website use in small-sized firms. Column event time is for each group relative to when they first participate in the treatment. In this case, *event time* $= 0$ corresponds to the *on impact effect*, i.e. email or website used by firm i, and *event time* $= -1$ is the effect in the period before firm i becomes treated. Panel I and II. represent the estimates of group time treatment effects driven by email usage and website usage, respectively. The dependent variables are expressed in logarithms. Inference: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$



(a) Small-sized: email effect on Operational Revenues



(b) Small-sized: email effect on Sales

Figure 4: Group-time average treatment effects for small-sized firms: (a) Operational revenues and (b) Sales.

Additionally, we check for of possible violations of parallel trends based on Roth (2019) and make use of *pretrends*[12] package in R. As it is clear in Table 6, each individual specification raises a probability of parallel trends assumption close to 0.1. In Appendix A.3.1 the same test is employed for the medium-sized firms sample and the results are shown briefly in Table 10.

[12]https://github.com/jonathandroth/pretrends

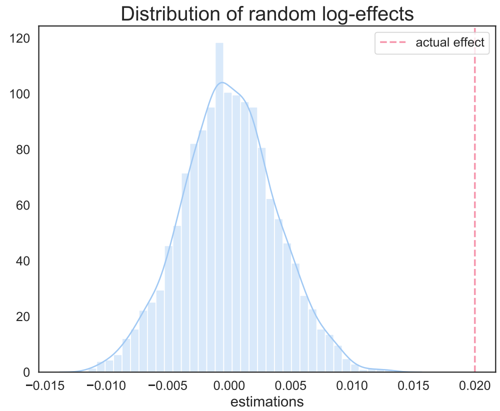
Variable	Likelihood of Failure (Small-sized firms - Email)	Likelihood of Failure (Small-sized firms - Website)
Operational Revenues	0.1024	0.0753
Sales	0.1006	0.1006
Gross Profits	0.1027	0.0760
Labor Productivity	0.0989	0.0699
Intangible Share	0.0806	0.0626

Table 6: Probability of parallel trends assumption failure regarding small-sized firms for all specifications.

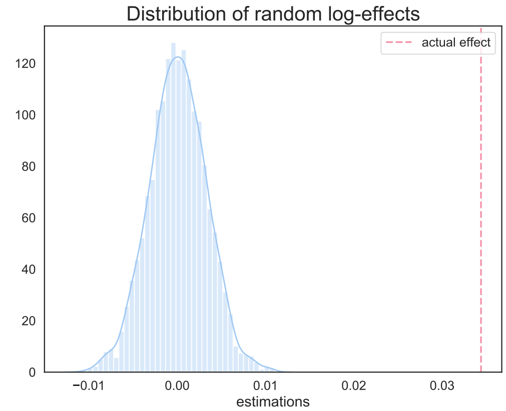
4.2.3 Placebo test

In this section we perform a randomization process across our sample to test whether our baseline is significantly different from a random allocation of the treatment (email and website). To achieve this we design a random permutation of the initial dataset and more specifically in the allocation of download speeds for each small and medium firm. In this context we assign firms with speeds that do not correspond to their actual broadband service and compare the distribution of the estimated coefficients with our baseline. In this process we construct again the interaction terms $log(speed) \times email$ and $log(speed) \times website$ and use our baseline model. We repeat this exercise 3,000 times, and plot the coefficients of interest versus our baseline estimators.

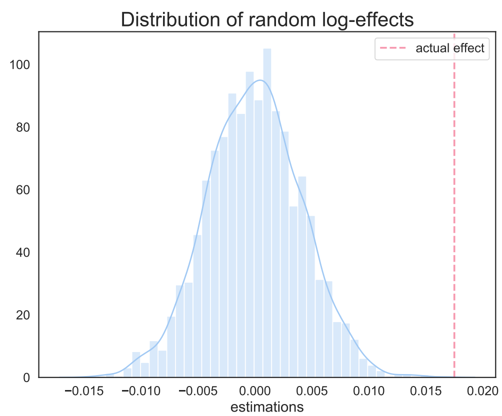
Figures 5 and 14 illustrate the distributions of the estimated placebo coefficients obtained by our baseline model for the small-sized firms. In particular, Figure 5 presents the impact of the interaction variable speed X *email* on the four economic variables that have been found to be strongly linked with broadband access. The dashed red line denotes the actual estimate of our benchmark model. For all four effects economic variables, the true estimate lies outside the 99.9% confidence interval. We obtain very similar results with the *website* treatment variable for small firms (Figure 14). The results from this process for medium sized firms is also presented in Figure 12 and Figure 13 indicating that the randomization process is less convincing for the estimated coefficients from our baseline compared to the smaller firms.



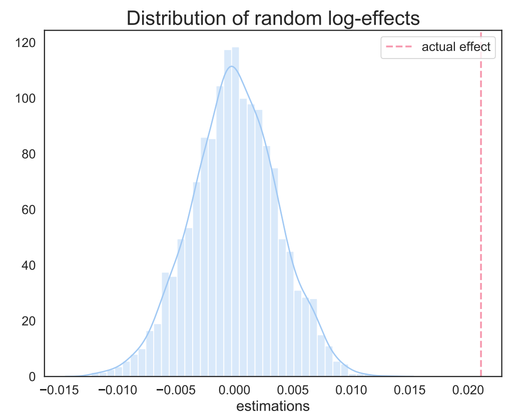
(a) Placebo estimations in small-sized firms: effects of $log(speed) \times email$ on turnover



(b) Placebo estimations in small-sized firms: effects of $log(speed) \times email$ on total sales



(c) Placebo estimations in small-sized firms: effects of $log(speed) \times email$ on gross profits



(d) Placebo estimations in small-sized firms: effects of $log(speed) \times email$ on labor productivity

Figure 5: Placebo estimations in small-sized firms: effects of $log(speed) \times email$ and actual effect based on our baseline model.

5 Conclusions

In this study we looked into into the effects of the improved broadband infrastructure on business performance for a representative sample of firms in Greece for the period 2002-2017. In this process we exploit the ADSL/VDSL technology upgrades and usage data, to infer the effects of broadband diffusion on business activity.

We first look into a correlational specification for broadband availability which appears unrelated with business performance. When we integrate adoption measures and find strong links with key financial variables including turnover, profits, sales and labor productivity are positively affected. Our baseline model indicates that a connection speed doubling for subscribing firms, affects turnover by 2.1-8.4 pp, sales by 2.0-8.4 pp, profits by 0- 3.0 pp and labor productivity by 2.4- 7.2 pp for adopting small businesses. The results are not statistically significant for medium-sized firms across the range of tests we looked into .

We test these estimates through different specifications which include spatial controls, randomization of the treatment and an even-study design. We find that the links remain strong for the key financial outcomes of small firms but not for medium firms.

Given the prevalence of small firms and their importance across most economies, these results suggest that the focus on broadband availability should be reconsidered with a mix of policies aimed at productive adoption and use of the services by small firms. Several policies including the provision of discounted vouchers for broadband access, training and skill development have been used so far and should be further developed in this direction.

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Appendix A

A.1 ORBIS data

In addition to the summary statistics presented in subsection 3.1, we include Table 7 which shows the descriptive statistics of Gross Profits of firms located in Attica and rest of the country (Periphery), respectively. As before, a similar same pattern is observed regarding the changes in the mean values.

Gross Profits in **Attica** (Millions of €)						
Year	Mean	Median	St.Deviation	Min	Max	n
2005	1.37	0.15	13.49	-2.27	307.17	792
2006	1.96	0.33	20.22	-3.85	915.07	4003
2007	3.11	0.52	24.02	-407.09	901.07	7270
2008	3.56	0.54	29.38	-589.82	1160.99	7773
2009	3.49	0.48	34.12	-325.27	1370.39	8150
2010	5.05	0.47	80.04	-193.28	5519.80	6056
2011	3.53	0.31	57.12	-161.72	5048.70	10811
2012	3.27	0.27	53.80	-163.21	4680.30	10901
2013	3.53	0.30	55.75	-48.36	4254.20	7689
2014	3.22	0.31	46.61	-179.75	3984.80	11012
2015	3.82	0.35	51.22	-158.03	3963.60	9846
2016	5.66	0.44	63.69	-168.86	3963.30	6496
2017	79.17	2.78	336.78	-3.64	3908.50	186
Gross Profits in **Periphery** (Millions of €)						
Year	Mean	Median	St.Deviation	Min	Max	n
2005	0.52	0.14	2.06	-0.72	25.48	435
2006	0.67	0.24	2.16	-2.24	37.20	1659
2007	0.90	0.33	2.35	-1.51	36.87	2806
2008	0.99	0.35	3.01	-5.41	52.64	3017
2009	0.89	0.31	2.76	-3.29	41.65	3168
2010	0.78	0.26	2.60	-14.25	54.05	3178
2011	0.69	0.21	2.91	-39.18	77.98	3323
2012	0.61	0.19	2.50	-15.98	56.71	2852
2013	0.65	0.20	2.34	-9.29	44.76	3597
2014	0.71	0.24	2.33	-9.99	48.01	4056
2015	0.84	0.28	3.02	-4.82	66.66	3173
2016	1.04	0.27	4.21	-1.13	80.16	1757
2017	6.72	0.25	21.15	-0.18	111.46	44

Table 7: Descriptive statistics of Gross Profits in millions in Attica and the Periphery of the Greek region. Summary statistics are expressed in millions.

Gross Profits in Millions of Euros						
Year	Mean	Median	St.Deviation	Min	Max	n
2005	1.07	0.15	10.91	-2.27	307.17	1227
2006	1.58	0.30	17.05	-3.85	915.07	5662
2007	2.49	0.46	20.46	-407.09	901.07	10076
2008	2.84	0.47	25.01	-589.82	1160.99	10790
2009	2.76	0.42	29.02	-325.27	1370.39	11318
2010	3.58	0.38	64.87	-193.28	5519.80	9234
2011	2.86	0.28	49.99	-161.72	5048.70	14134
2012	2.72	0.25	47.92	-163.21	4680.30	13753
2013	2.61	0.26	46.05	-48.36	4254.20	11286
2014	2.55	0.29	39.88	-179.75	3984.80	15068
2015	3.09	0.33	44.59	-158.03	3963.60	13019
2016	4.67	0.40	56.57	-168.86	3963.30	8253
2017	65.31	1.91	304.18	-3.64	3908.50	230

Table 8: Descriptive Statistics of gross profits per year. Values are expressed in millions of Euros.

Turnover in Millions of Euros						
Year	Mean	Median	St.Deviation	Min	Max	n
2005	5.90	0.44	77.58	-0.0	2331.47	1227
2006	5.84	0.99	62.50	-0.0	3287.53	5662
2007	11.07	1.52	97.22	-0.0	5154.17	10076
2008	13.86	1.57	141.17	-0.0	5937.93	10797
2009	12.18	1.39	126.34	-0.0	6030.38	11325
2010	14.39	1.28	169.34	-0.0	8512.11	9238
2011	13.76	0.93	186.61	-0.0	9307.58	14138
2012	13.72	0.81	202.90	-0.0	10468.87	13757
2013	12.11	0.85	182.18	-0.0	9674.32	11300
2014	12.01	0.80	175.80	-0.0	9489.21	15104
2015	12.39	0.86	157.00	-0.0	7312.37	13463
2016	15.89	1.07	168.40	-0.0	6648.80	10362
2017	60.98	2.52	440.04	0.0	7994.69	1767

Table 9: Descriptive Statistics of turnover per year. Values are expressed in millions of Euros.

A.2 Network Data

The structure of our dataset is more clear when we zoom over dense cities like Athens. ADSL street cabinets and firms are shown in Figures 6 and 7 and show the network and assignment of firms in Attica region and in the center of Athens, respectively.

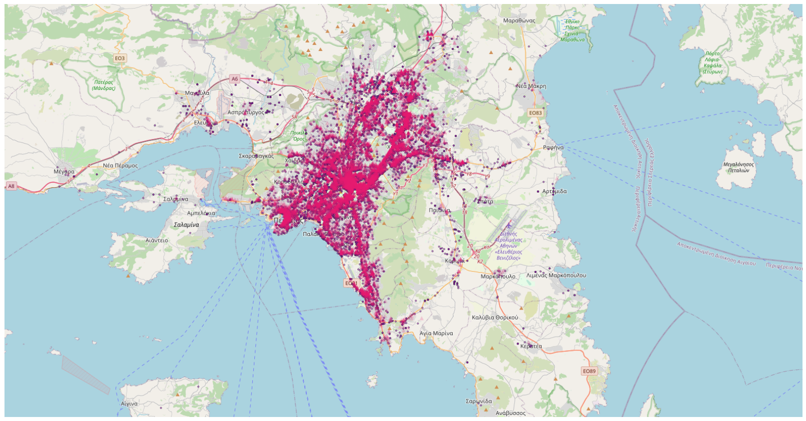


Figure 6: Firms' location based on ORBIS finalized dataset in Attica region. The darker dots indicate the firms' exact location of all company categories and triangle-shape points in pink denote the location of street cabinets.

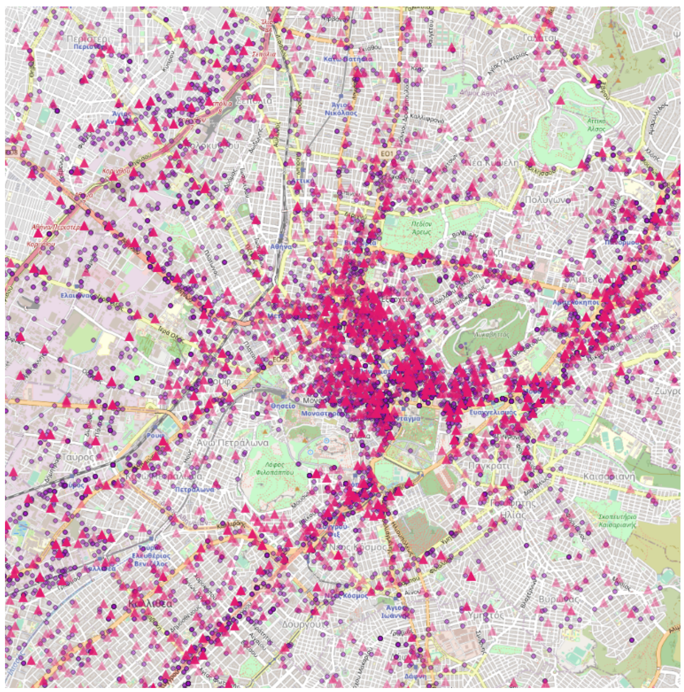
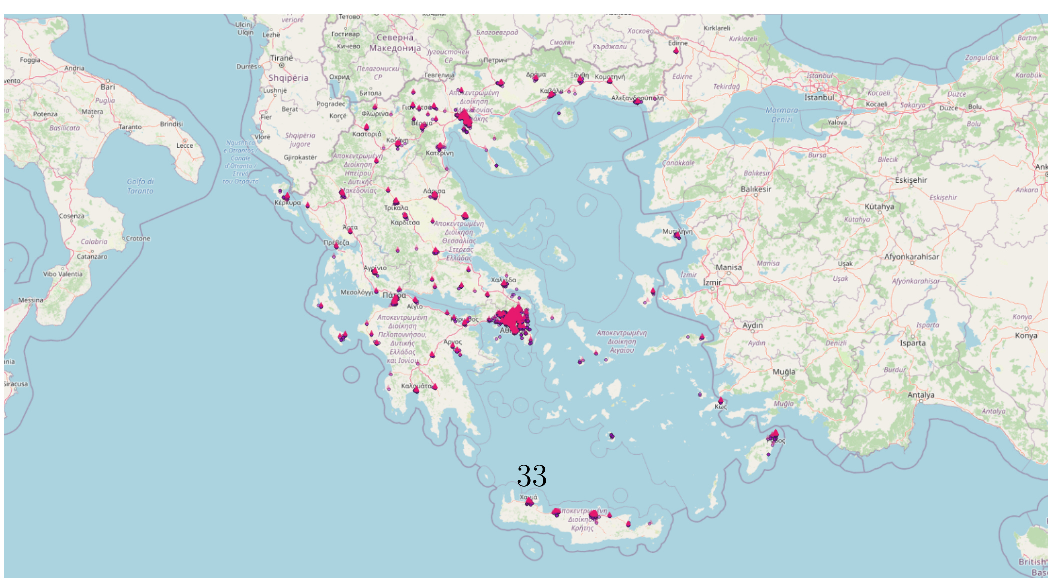


Figure 7: Longitudinal data for firms and street cabinets in the center of Athens. Firm-level data and street cabinets points are shown in dark dots and light-pink triangles, respectively.



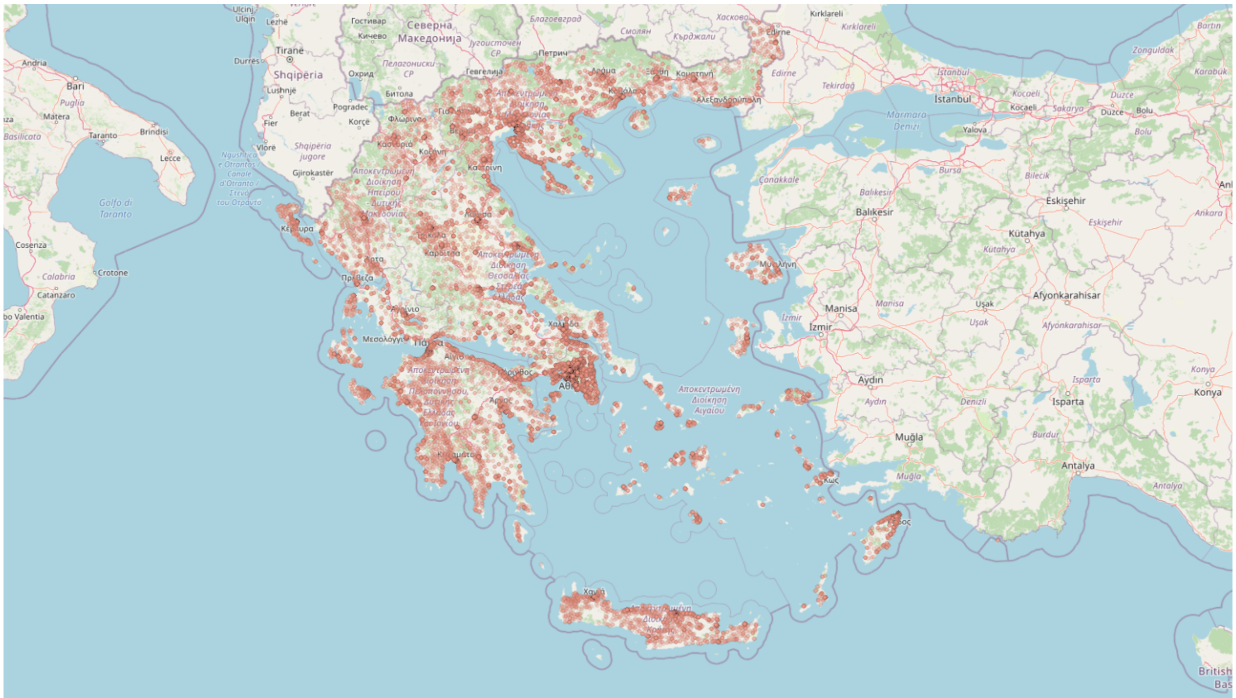
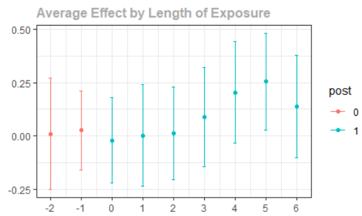


Figure 9: ADSL Street Cabinets representation given the initial longitudinal data covering the Greek area.

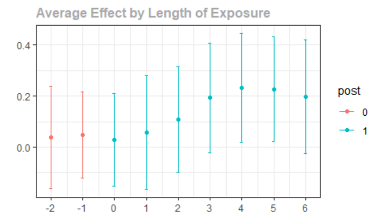
A.3 Results

A.3.1 Difference-in-Differences results

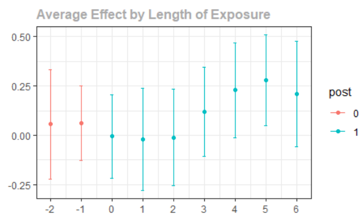
The DiD results for regarding the medium-sized firms and the impact of email and website adoption are presented in Table 10 below.



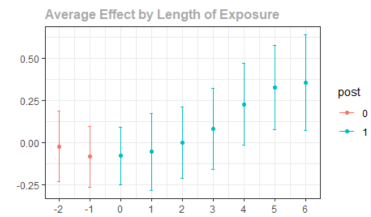
(a) Medium-sized: email effect on Operational Revenue



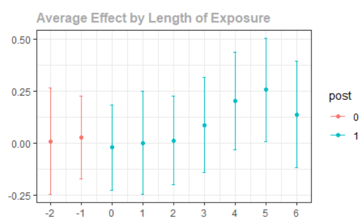
(b) Medium-sized: email effect on Sales



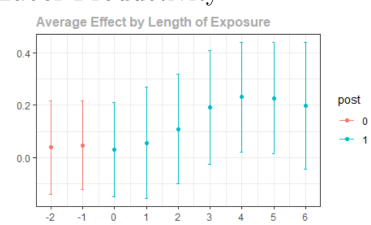
(c) Medium-sized: email effect on Gross Profits



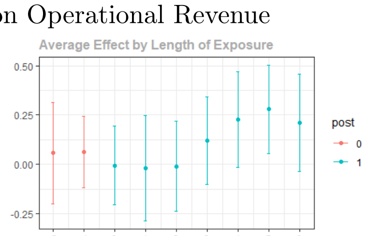
(d) Medium-sized: email effect on Labor Productivity



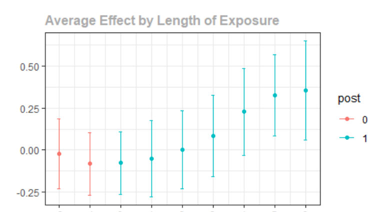
(e) Medium-sized: website effect on Operational Revenue



(f) Medium-sized: website effect on Sales



(g) Medium-sized: website effect on Gross Profits



(h) Medium-sized: website effect on Labor Productivity

Figure 10: Summarized group-time average treatment effects for medium-sized firms

In section A.3.2, the respective results referring only in medium-sized businesses are presented.

	Turnover	Sales	Gross Profits	Labor Productivity	Intangible Share
DiD in Medium sized					
I. Email use					
Overall group-time average treatment effect (ATT):					
	0.0972	0.1491*	0.1142	0.1233	0.8452***
	(0.0710)	(0.0630)	(0.0739)	(0.0692)	(0.1894)
Dynamic Effects:					
event time					
-2	0.0090	0.0385	0.0565	-0.0219	-0.0347
	(0.0996)	(0.0725)	(0.1042)	(0.0790)	(0.2219)
-1	0.0270	0.0470	0.0631	-0.0819	-0.0157
	(0.0706)	(0.0611)	(0.0712)	(0.0689)	(0.2063)
0	-0.0207	0.0295	-0.0059	-0.0779	-0.0187
	(0.0761)	(0.0655)	(0.0794)	(0.0653)	(0.2145)
1	0.0021	0.0565	-0.0207	-0.0537	0.1480
	(0.0913)	(0.0808)	(0.0975)	(0.0872)	(0.2618)
2	0.0134	0.1091	-0.0104	0.0013	0.6074
	(0.0831)	(0.0748)	(0.0916)	(0.0806)	(0.2648)
3	0.0880	0.1923	0.1182	0.0843	0.7820*
	(0.0884)	(0.0777)	(0.0847)	(0.0911)	(0.2532)
4	0.2037	0.2317*	0.2286	0.2280	0.9764**
	(0.0910)	(0.0776)	(0.0901)	(0.0919)	(0.2478)
5	0.2559*	0.2268*	0.2793*	0.3259*	1.6750***
	(0.0865)	(0.0743)	(0.0869)	(0.0948)	(0.2703)
6	0.1380	0.1981	0.2101	0.3548*	1.7465***
	(0.0913)	(0.0807)	(0.1005)	(0.1081)	(0.2706)
II. Website use					
Overall group-time average treatment effect (ATT):					
	0.0338	0.0547	0.0377	-0.0104	0.2166
	(0.0380)	(0.0355)	(0.0373)	(0.0359)	(0.1428)
Dynamic Effects:					
event time					
-2	0.0147	0.0183	0.0476	-0.0374	0.1501
	(0.0609)	(0.0426)	(0.0594)	(0.0462)	(0.1715)
-1	0.0514	0.0571	0.0611	-0.0499	0.0145
	(0.0435)	(0.0392)	(0.0442)	(0.0405)	(0.1653)
0	-0.0522	-0.0216	-0.0234	-0.0654	-0.0380
	(0.0451)	(0.0397)	(0.0428)	(0.0399)	(0.1477)
1	-0.0060	0.0211	-0.0041	-0.0641	-0.0944
	(0.0543)	(0.0476)	(0.0492)	(0.0452)	(0.1813)
2	0.0132	0.0572	-0.0025	-0.0733	0.1131
	(0.0517)	(0.0450)	(0.0491)	(0.0423)	(0.1756)
3	0.0498	0.0892	0.0525	-0.0218	0.1700
	(0.0486)	(0.0423)	(0.0507)	(0.0478)	(0.1936)
4	0.1219	0.1191	0.1058	0.0474	0.1820
	(0.0467)	(0.0470)	(0.0460)	(0.0461)	(0.1787)
5	0.1017	0.0855	0.1027	0.0493	0.5665*
	(0.0490)	(0.0460)	(0.459)	(0.0493)	(0.1838)
6	0.0084	0.0322	0.0327	0.0552	0.6172*
	(0.0542)	(0.0500)	(0.0500)	(0.0533)	(0.1872)

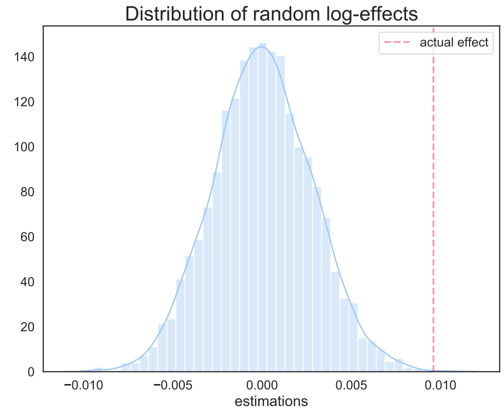
Figure 11: Aggregated group-time average treatment effects of email and website use in medium-sized firms. Column event time is for each group relative to when they first participate in the treatment. In this case, *event time* = 0 corresponds to the *on impact effect*, i.e. email or website used by firm i, and *event time* $= -1$ is the effect in the period before firm i becomes treated. Panel I and II. represent the estimates of group time treatment effects driven by email usage and website usage, respectively. The dependent variables are expressed in logarithms. Inference: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Variable	Likelihood of Failure (Medium-sized firms - Email)	Likelihood of Failure (Medium-sized firms - Website)
Operational Revenues	0.1237	0.0977
Sales	0.1274	0.0962
Gross Profits	0.1210	0.0953
Labor Productivity	0.1231	0.0952
Intangible Share	0.1182	0.0857

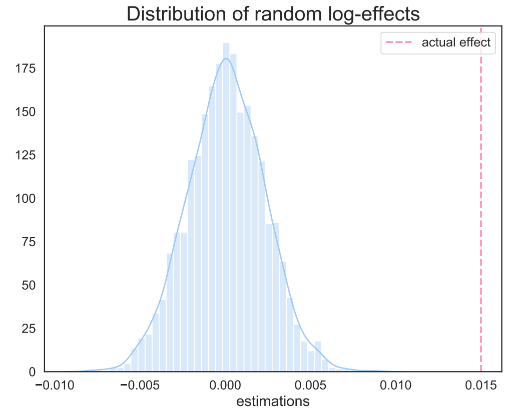
Table 10: Probability of parallel trends assumption failure regarding medium-sized firms for all specifications.

A.3.2 Placebo tests

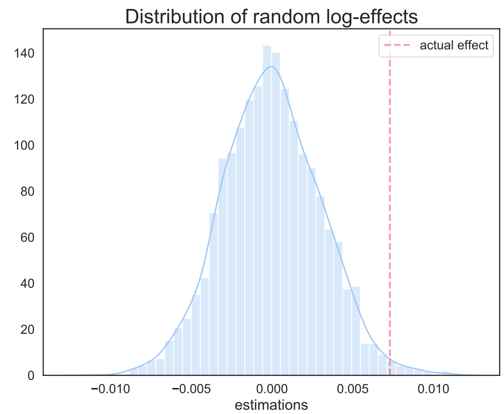
Results obtained by the placebo tests employed in medium-sized firms. In each plot the dashed line represents the actual coefficient estimation of the respective baseline model. The placebo estimations are distributed approximately around zero.



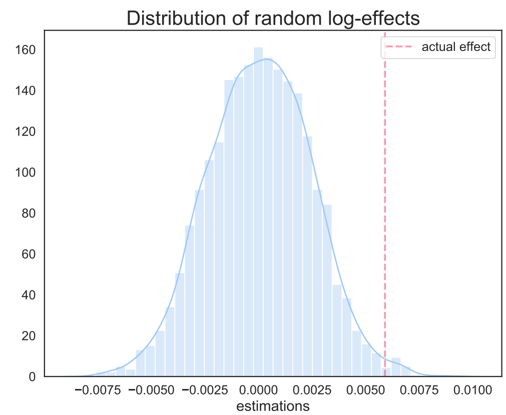
(a) Placebo estimations in medium-sized firms: effects of $log(speed) \times email$ on turnover



(b) Placebo estimations in medium-sized firms: effects of $log(speed) \times email$ on total sales



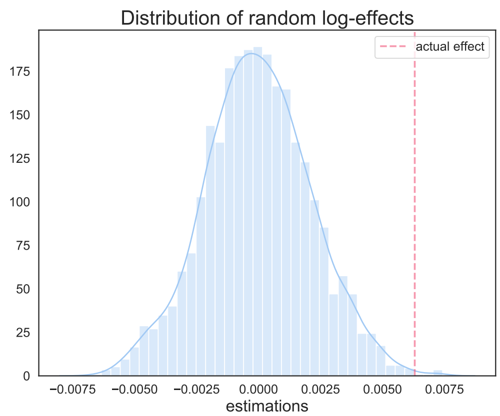
(c) Placebo estimations in medium-sized firms: effects of $log(speed) \times email$ on gross profits



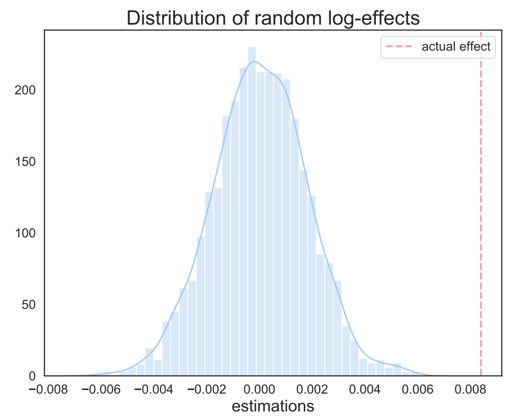
(d) Placebo estimations in medium-sized firms: effects of $log(speed) \times email$ on labor productivity

Figure 12: Placebo estimations in medium-sized firms: effects of $log(speed) \times email$ and actual effect based on our baseline model

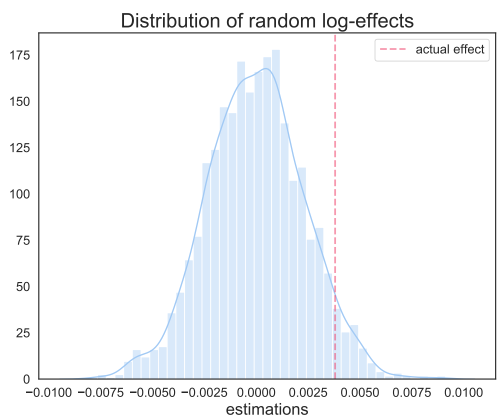
Similar findings are presented, when the random effects specification is employed. First, we present the placebo results for the small as well as the medium-sized firms studying the log-effects in the randomized experiment of the email and website use, respectively.



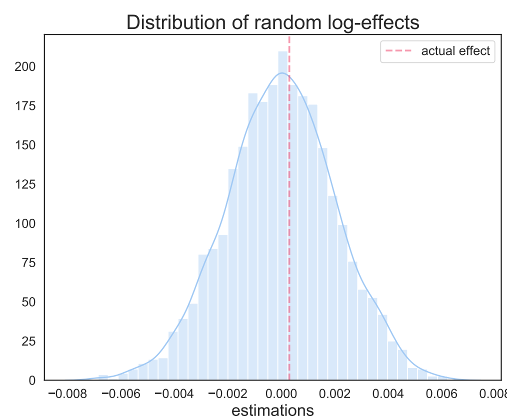
(a) Placebo estimations in medium-sized firms: effects of $log(speed) \times website$ on turnover



(b) Placebo estimations in medium-sized firms: effects of $log(speed) \times website$ on total sales

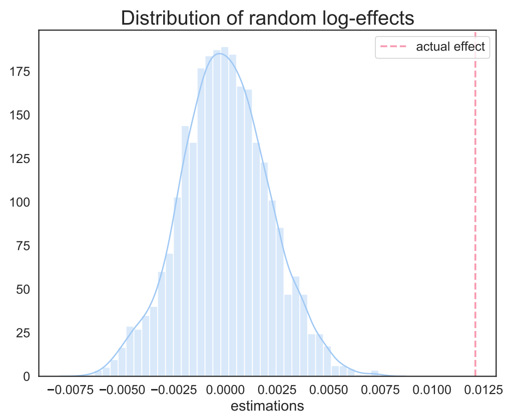


(c) Placebo estimations in medium-sized firms: effects of $log(speed) \times website$ on gross profits

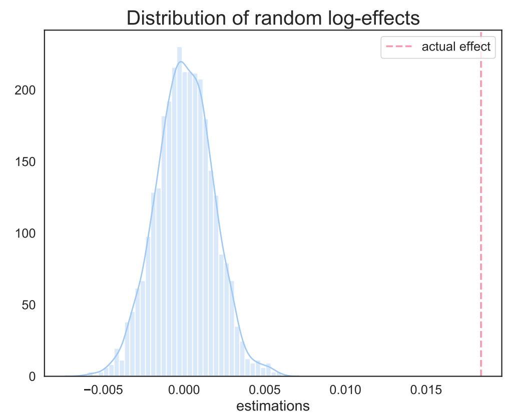


(d) Placebo estimations in medium-sized firms: effects of $log(speed) \times website$ on labor productivity

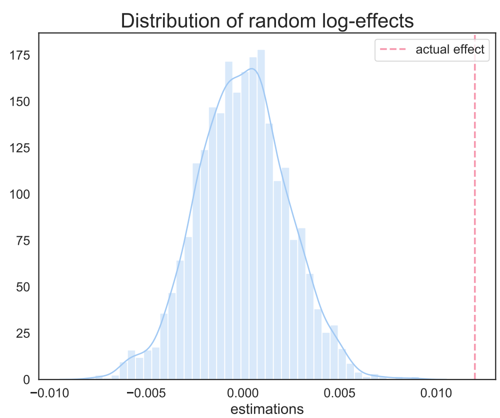
Figure 13: Placebo estimations in medium-sized firms: effects of $log(speed) \times website$ and actual effect based on our baseline model



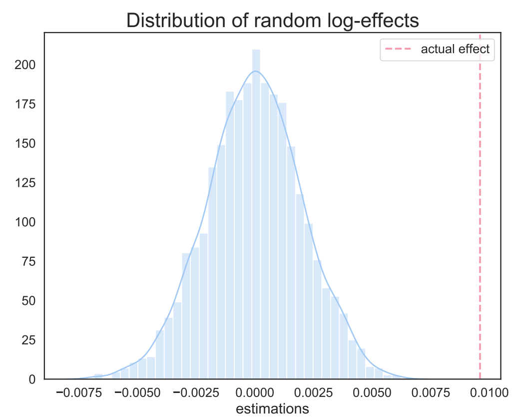
(a) Placebo estimations in small-sized firms: effects of $log(speed) \times website$ on turnover



(b) Placebo estimations in small-sized firms: effects of $log(speed) \times website$ on total sales



(c) Placebo estimations in small-sized firms: effects of $log(speed) \times website$ on gross profits



(d) Placebo estimations in small-sized firms: effects of $log(speed) \times website$ on labor productivity

Figure 14: Placebo estimations in small-sized firms: effects of $log(speed) \times website$ and actual effect based on our baseline model

A.3.3 Baseline results

	(1)	(2)	(3)	(4)
Turnover				
Activation Boundary (AB) = 1	-0.258***	0.020	0.016	-0.029
	(0.011)	(0.018)	(0.017)	(0.019)
Observations	104,854	103,362	103,361	88,635
R-squared	0.005	0.876	0.879	0.886
Sales				
Activation Boundary (AB) = 1	-0.259***	0.021	0.017	-0.028
	(0.011)	(0.018)	(0.017)	(0.019)
Observations	104,872	103,376	103,375	88,648
R-squared	0.005	0.876	0.879	0.886
Gross Profits				
Activation Boundary (AB) = 1	-0.171***	-0.026	-0.026	-0.061**
	(0.011)	(0.023)	(0.023)	(0.026)
Observations	103,975	102,424	102,423	87,428
R-squared	0.002	0.782	0.785	0.798
Labor Productivity				
Activation Boundary (AB) = 1	-0.094***	0.004	0.002	-0.019
	(0.009)	(0.023)	(0.023)	(0.024)
Observations	70,658	69,426	69,426	67,894
R-squared	0.001	0.784	0.785	0.799
Intangible share				
Activation Boundary (AB) = 1	-0.259***	0.021	0.017	-0.028
	(0.011)	(0.018)	(0.017)	(0.019)
Observations	104,872	103,376	103,375	88,648
R-squared	0.005	0.876	0.879	0.886
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 11: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
AB X Adoption	-0.062	-0.085***	-0.044**	0.043
	(0.044)	(0.022)	(0.022)	(0.028)
Observations	103,269	101,843	101,842	87,478
R-squared	0.011	0.877	0.880	0.886
Sales				
AB X Adoption	-0.062	-0.085***	-0.043**	0.045
	(0.044)	(0.022)	(0.022)	(0.028)
Observations	103,285	101,855	101,854	87,491
R-squared	0.011	0.877	0.880	0.886
Gross Profits				
AB X Adoption	-0.015	-0.077***	-0.037	0.063
	(0.045)	(0.030)	(0.030)	(0.039)
Observations	102,416	100,926	100,925	86,298
R-squared	0.004	0.783	0.785	0.798
Labor Productivity				
AB X Adoption	-0.104***	-0.041	-0.031	0.003
	(0.039)	(0.027)	(0.027)	(0.035)
Observations	69,572	68,378	68,378	66,957
R-squared	0.013	0.785	0.785	0.799
Intangible share				
AB X Adoption	-0.011***	-0.001	-0.000	-0.001
	(0.003)	(0.003)	(0.003)	(0.004)
Observations	106,770	105,463	105,462	89,481
R-squared	0.001	0.685	0.686	0.703
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
AB X Adoption X small	0.043***	0.052***	0.023***	0.021**
	(0.004)	(0.008)	(0.008)	(0.009)
Observations	103,269	101,843	101,842	87,478
R-squared	0.335	0.878	0.880	0.886
Sales				
AB X Adoption X small	0.043***	0.052***	0.023***	0.020**
	(0.004)	(0.008)	(0.008)	(0.009)
Observations	103,285	101,855	101,854	87,491
R-squared	0.335	0.878	0.880	0.886
Gross Profits				
AB X Adoption X small	0.040***	0.055***	0.031***	0.030**
	(0.005)	(0.011)	(0.011)	(0.013)
Observations	102,416	100,926	100,925	86,298
R-squared	0.247	0.784	0.785	0.798
Labor Productivity				
AB X Adoption X small	0.007	0.016	0.017	0.024*
	(0.005)	(0.011)	(0.011)	(0.012)
Observations	69,572	68,378	68,378	66,957
R-squared	0.071	0.785	0.785	0.799
Intangible share				
AB X Adoption X small	-0.001***	0.000	-0.000	-0.003**
	(0.000)	(0.001)	(0.001)	(0.001)
Observations	106,770	105,463	105,462	89,481
R-squared	0.002	0.685	0.686	0.703
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
AB X Adoption X medium	0.226***	-0.246***	-0.094***	-0.046
	(0.022)	(0.033)	(0.035)	(0.038)
Observations	104,854	103,362	103,361	88,635
R-squared	0.041	0.876	0.879	0.886
Sales				
AB X Adoption X medium	0.227***	-0.247***	-0.095***	-0.047
	(0.022)	(0.033)	(0.035)	(0.038)
Observations	104,872	103,376	103,375	88,648
R-squared	0.041	0.876	0.879	0.886
Gross Profits				
AB X Adoption X medium	0.228***	-0.148***	-0.043	-0.071
	(0.022)	(0.045)	(0.046)	(0.052)
Observations	103,975	102,424	102,423	87,428
R-squared	0.029	0.782	0.785	0.798
Labor Productivity				
AB X Adoption X medium	0.049**	-0.147***	-0.105**	-0.055
	(0.019)	(0.043)	(0.045)	(0.049)
Observations	70,658	69,426	69,426	67,894
R-squared	0.004	0.785	0.785	0.799
Intangible share				
1.medium#1.cuttoff_final	0.002	-0.016***	-0.009**	0.008
	(0.002)	(0.004)	(0.004)	(0.005)
Observations	108,363	107,005	107,004	90,638
R-squared	0.001	0.684	0.685	0.704
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
AB X Adoption X medium	0.053***	-0.025***	-0.017**	-0.009
	(0.005)	(0.008)	(0.008)	(0.009)
Observations	103,269	101,843	101,842	87,478
R-squared	0.045	0.877	0.880	0.886
Sales				
AB X Adoption X medium	0.053***	-0.025***	-0.017**	-0.010
	(0.005)	(0.008)	(0.008)	(0.009)
Observations	103,285	101,855	101,854	87,491
R-squared	0.045	0.877	0.880	0.886
Gross Profits				
AB X Adoption X medium	0.053***	-0.013	-0.009	-0.017
	(0.005)	(0.010)	(0.010)	(0.012)
Observations	102,416	100,926	100,925	86,298
R-squared	0.029	0.783	0.785	0.798
Labor Productivity				
AB X Adoption X medium	0.013***	-0.027***	-0.025**	-0.011
	(0.004)	(0.010)	(0.010)	(0.011)
Observations	69,572	68,378	68,378	66,957
R-squared	0.015	0.785	0.785	0.799
Intangible share				
AB X Adoption X medium	0.000	-0.002**	-0.002**	0.002*
	(0.000)	(0.001)	(0.001)	(0.001)
Observations	106,770	105,463	105,462	89,481
R-squared	0.001	0.685	0.686	0.703
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
Speed (available in log Mbps)	-0.148***	-0.004	-0.001	0.002
	(0.004)	(0.003)	(0.003)	(0.005)
Observations	102,447	100,998	100,998	86,865
R-squared	0.013	0.862	0.865	0.873
Sales				
Speed (available in log Mbps)	-0.148***	-0.004	-0.001	0.002
	(0.004)	(0.003)	(0.003)	(0.005)
Observations	102,447	100,998	100,998	86,865
R-squared	0.013	0.862	0.865	0.873
Gross Profits				
Speed (available in log Mbps)	-0.106***	-0.003	-0.000	-0.004
	(0.004)	(0.004)	(0.004)	(0.006)
Observations	101,617	100,115	100,115	85,748
R-squared	0.006	0.763	0.766	0.781
Labor Productivity				
Speed (available in log Mbps)	-0.138***	-0.003	-0.003	-0.001
	(0.004)	(0.003)	(0.003)	(0.005)
Observations	68,843	67,621	67,621	66,346
R-squared	0.018	0.779	0.780	0.795
Intangible share				
Speed (available in log Mbps)	-0.002***	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.001)
Observations	105,796	104,488	104,488	88,765
R-squared	0.000	0.682	0.683	0.702
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
Digital use X Speed	0.073***	0.099***	0.065***	-0.014
	(0.010)	(0.005)	(0.005)	(0.009)
Observations	102,438	100,993	100,993	86,859
R-squared	0.133	0.862	0.865	0.873
Sales				
Digital use X Speed	0.073***	0.099***	0.065***	-0.014
	(0.010)	(0.005)	(0.005)	(0.009)
Observations	102,447	100,998	100,998	86,865
R-squared	0.133	0.862	0.865	0.873
Gross Profits				
Digital use X Speed	0.040***	0.061***	0.030***	-0.062***
	(0.010)	(0.007)	(0.007)	(0.011)
Observations	101,617	100,115	100,115	85,748
R-squared	0.101	0.763	0.766	0.781
Labor Productivity				
Digital use X Speed	0.002**	0.004***	0.004***	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	105,796	104,488	104,488	88,765
R-squared	0.001	0.683	0.684	0.702
Intangible share				
Digital use X Speed	-0.002***	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.001)
Observations	105,796	104,488	104,488	88,765
R-squared	0.000	0.682	0.683	0.702
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 17: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
Digital use X Speed X small	0.055***	0.026**	0.046***	0.084***
	(0.018)	(0.011)	(0.011)	(0.018)
Observations	102,438	100,993	100,993	86,859
R-squared	0.388	0.863	0.865	0.873
Sales				
Digital use X Speed X small	0.055***	0.026**	0.046***	0.084***
	(0.018)	(0.011)	(0.011)	(0.018)
Observations	102,447	100,998	100,998	86,865
R-squared	0.388	0.863	0.865	0.873
Gross Profits				
Digital use X Speed X small	0.032*	0.039***	0.052***	-0.013
	(0.019)	(0.014)	(0.014)	(0.023)
Observations	101,617	100,115	100,115	85,748
R-squared	0.283	0.764	0.766	0.781
Labor Productivity				
Digital use X Speed X small	-0.010***	-0.008***	-0.007***	-0.010***
	(0.002)	(0.001)	(0.001)	(0.002)
Observations	105,796	104,488	104,488	88,765
R-squared	0.001	0.683	0.684	0.702
Intangible share				
Digital use X Speed X small	-0.002***	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.001)
Observations	105,796	104,488	104,488	88,765
R-squared	0.000	0.682	0.683	0.702
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

	(1)	(2)	(3)	(4)
Turnover				
Digital use X Speed X medium	-0.050**	-0.036***	-0.011	-0.059***
	(0.021)	(0.011)	(0.011)	(0.018)
Observations	102,438	100,993	100,993	86,859
R-squared	0.175	0.862	0.865	0.873
Sales				
Digital use X Speed X medium	-0.050**	-0.036***	-0.011	-0.059***
	(0.021)	(0.011)	(0.011)	(0.018)
Observations	102,447	100,998	100,998	86,865
R-squared	0.175	0.862	0.865	0.873
Gross Profits				
Digital use X Speed X medium	-0.010	-0.036**	-0.004	0.073***
	(0.022)	(0.015)	(0.015)	(0.023)
Observations	101,617	100,115	100,115	85,748
R-squared	0.131	0.763	0.766	0.781
Labor Productivity				
Digital use X Speed X medium	-0.191***	-0.062***	-0.063***	-0.069***
	(0.037)	(0.024)	(0.024)	(0.025)
Observations	68,843	67,621	67,621	66,346
R-squared	0.043	0.779	0.780	0.795
Intangible share				
Digital use X Speed X medium	0.008***	0.005***	0.005***	0.007***
	(0.002)	(0.001)	(0.001)	(0.002)
Observations	105,796	104,488	104,488	88,765
R-squared	0.001	0.683	0.684	0.702
Firm FE	NO	YES	NO	NO
Year FE	NO	YES	NO	NO
Firm X Comp_Cat FE	NO	NO	YES	NO
Year X Comp_Cat FE	NO	NO	YES	NO
Firm X Nace_code X Comp_Cat FE	NO	NO	NO	YES
Year X Region X Comp_Cat FE	NO	NO	NO	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 19: OLS estimates of broadband upgrade availability (ADSL or VDSL) within the Activation Boundary (AB) and the interaction with the adoption in each LE/cabinet for small and medium firms. All variables are expressed in logarithms. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1