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Fiber deployment in Spain

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Abstract: Next generation access networks will be critical for future economic growth and access to these infrastructures will have major consequences for territorial and social cohesion. This paper examines the economic and regulatory determinants that serve as incentives for operators to invest in fiber-to-the-home technology. We draw on a dataset comprising 6,063 Spanish municipalities with access to broadband services to examine the incumbents' (Telefónica) deployment of fiber in the period 2010-13. We show that local loop unbundling competition had a strong positive impact on Telefónica's fiber deployment, while bitstream competition had a negative effect. Moreover, the incumbent was more likely to invest in municipalities with a large presence of cable operators. We also consider how the municipalities' sociodemographic characteristics affected the operator's deployment decision. While market size and population density had a positive effect on investment, the level of unemployment and the percentage of elderly population had a negative impact.

JEL Codes: L12, L13, L51, L52, L96.

Keywords: Fiber, Broadband, Competition, Regulation, Telecommunications, Municipalities.

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1. Introduction

The growing demand for high-speed Internet services has induced the world's leading telecommunications operators to deploy next generation access (NGA) networks¹. Despite taking this step, the extraordinary cost of these infrastructures may result in a large part of the population being left without access to high-speed Internet, and this has given rise to growing concerns about the potential impact this dual evolution of the market may have in terms of territorial and social cohesion.

In the European Union (EU), recognition of this problem led to the adoption of the Digital Agenda for Europe in 2010, whereby the Union committed itself to ensuring that by 2020 there should be universal coverage of networks that support broadband speeds greater than 30 Mbps and that half of all European households would subscribe to connections over 100 Mbps. In September 2016, this objective was further extended so as to ensure that by 2025 all European households should enjoy access to connectivity offering at least 100 Mbps². As a direct result of this, European regulators have introduced modifications to sector legislation in an attempt at reaching these objectives. However, the measures adopted in recent years are not easily evaluated given the absence of studies examining the factors that might influence the operators' investment decisions. This paper seeks to fill this gap by analyzing the fiber-to-the-home (FTTH) deployment made by Telefónica in Spain between 2010 and 2013, a period in which the incumbent operator was the first and only company to invest in this technology in the country.

An essential aspect in understanding the operators' investment in NGA is determining just how their decisions are affected by the regulation of access to the incumbent's legacy network and to the NGA networks. Following the liberalization of the telecommunications sector in the mid-nineties, the difficulties encountered in persuading new entrants to invest outside the most profitable metropolitan areas of European cities led the European Commission to initiate local loop unbundling (LLU). By so doing, the entrants were able to install their equipment in the incumbent's

¹ There are three types of NGA broadband: VDSL over copper (with a network topology known as FTTN/FTTC), FTTP (which comprises both fiber to the home – FTTH - and fiber to the building - FTTB) and coaxial cable networks upgraded by the standard DOCSIS 3.0. The transmission capacity and speed of all these networks is less influenced by distance than it is in copper networks. The difference between fiber networks depends on the distance between the fiber end and the consumer's premises. For example, in Spain, Italy, Portugal and France, the fiber reaches the customer's home (FTTH), whilst in the UK, Germany and France it reaches a street cabinet (FTTC) from which a copper cable provides access.

² The European Commissions' (EC) Communication "Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society" states that by 2025, symmetrical connectivity must be provided at 1 Gigabit per second in strategic locations (public infrastructure and industrial areas), that there should be complete 5G coverage in urban centers and on main transport routes, and that all households should have Internet at speeds of at least 100 Mbps. In addition, the EC proposes a reform of the regulatory framework for electronic communications and suggests the creation of a European Broadband Fund.

switching facilities at a regulated wholesale price and to use the incumbent's terminal copper line to access the clients' premises. The introduction of LLU has meant that entrants can offer a differentiated service from that provided by the incumbent, and so gradually they have been able to erode its market share. In Europe, LLU regulation was justified on the grounds of the so-called ladder-of-investment, which considers that by providing entrants with different access options (e.g. local loop unbundling, bitstream and resale), they have incentives for the gradual increase in infrastructure investment³.

In line with this legacy-based infrastructure regulation, the European Commission considers that multilevel access to the NGA infrastructure of operators that enjoy significant market power may promote greater investment efforts by entrants. As a consequence, it has recommended an extension of its traditional access policy to the new networks. In recent years, various EU countries (including Austria, Belgium, Denmark, Finland, Italy, Netherlands and Sweden) have introduced regulations on NGA wholesale access, while others have chosen not to regulate this wholesale service (France and Portugal)⁴. Despite this, there is very little evidence as to how operators are reacting to these regulatory strategies.

The theoretical literature has examined several regulatory frameworks that can be used to promote investment in NGA networks. Some papers have analyzed the relation between copper and fiber access regulations and their impact on the migration from old to new networks (Bourreau et al., 2012; Bourreau et al., 2014; Nitsche and Wiethaus, 2011; Briglauer and Vogelsang, 2011; Brito et al., 2010; Inderst and Peitz, 2014). For example, Bourreau et al., (2012) identified three effects that can influence operators' incentives to invest: (1) a replacement effect: if the legacy access charge is high, entrants accelerate their investment in the new infrastructure; (2) a wholesale revenue effect: if the incumbent invests in a higher quality network, it loses some wholesale profits; and (3) a business migration effect: when the access price to the legacy network is low, the prices for the services that rely on this network are also low. Hence, in order to encourage customers to switch from old to new technology, the operators deploying new networks have to differentiate their services. Overall, this stream of literature considers that NGA investments can reduce the revenues obtained with the legacy infrastructure, which might reduce the incentive to invest in new networks. Similarly, extending the access regulations to the new infrastructure may negatively affect the profitability of fiber deployment.

In Spain, in the period analyzed, Telefónica (the former monopoly) was the first and only operator to deploy fiber. Although initially the wholesale service of this new

³ In the US, by contrast, in 2005 the regulator eliminated most elements of the unbundling regime, considering that the existence of an almost nationwide duopoly was enough to generate competition (Briglauer et al., 2014; Vogelsang, 2015).

⁴ See BEREC, 2016.

technology was not regulated, Telefónica was required to provide other operators with access to its ducts and civil infrastructure. In contrast, entrants could access Telefónica's legacy copper network via different wholesale services: LLU and bitstream. Against this backdrop, our empirical model analyzes how LLU and bitstream competition at the municipality level influenced Telefónica's fiber deployment.

Similarly, during the period of analysis, cable operators held a strong presence in certain Spanish regions, their networks being deployed between 1995 and 2000. Moreover, once Telefónica initiated its FTTH roll-out, cable operators had already upgraded their networks, so that they could support very high speeds. Taking this into account, our paper also considers the impact of existing cable competition in a municipality on Telefónica's investment decisions. Finally, we also examine how local socioeconomic characteristics determined investment decisions.

We use panel data on the incumbent operator's FTTH deployment in 6,063 Spanish municipalities with broadband from the first semester of 2010 to the first semester of 2013. Our results show that the regulation of access to Telefónica's network was a key determinant in the operator's investment strategy. While LLU competition had a strong positive impact on Telefónica's fiber deployment, bitstream competition had a negative effect. In this regard, it should be stressed that LLU operators had been Telefónica's fiercest competitors since market liberalization in 1998, and in those years managed to attract a large share of the incumbent's consumers. By deploying fiber in areas where LLU entry had been intense, Telefónica was able to differentiate its offer and appropriate some profits from its investment in NGA. Moreover, as the LLU wholesale price was low, the wholesale revenues foregone by investing in fiber were relatively small. By contrast, in areas where bitstream entry had been comparatively more prevalent, Telefónica showed less interest in deploying fiber. Finally, our results show some evidence of a positive relationship between the cable operators' market share and Telefónica's investments.

Our study of the sociodemographic characteristics of the municipalities reveals that market size, measured by the number of households and premises in the municipality, had a positive effect on the odds of fiber deployment. Similarly, the density of the population had a positive and significant effect. Finally, the level of unemployment and the percentage of elderly population in the municipality presented a negative impact. These results suggest that in addition to the competition variables, local market characteristics were an essential factor in determining Telefónica's investment strategy.

The rest of the paper proceeds as follows. The next section reviews the empirical literature on NGA investments. Section 3 explains the main characteristics of the Spanish market. Section 4 describes the data set. Section 5 explains the empirical strategy. Section 6 presents the results. And, finally, Section 7 concludes.

2. Review of the empirical literature

Studies of the determinants of NGA investment are scarce. A number of papers have analyzed LLU and next generation network (NGN) investments by drawing on data at the national level⁵. Most of these examine the validity of the ladder-of-investment approach, the strategy that regulates access to the incumbent operator's infrastructure (bitstream and LLU) so as to create service-based competition and promote facility-based competition in the long run⁶. Bacache et al. (2014) examine migration from old to new broadband infrastructure in 15 European Member States between 2002 and 2010, and show that unbundling regulations did not provide entrants with any incentives to invest in NGA. Briglauer (2015) and Briglauer et al., (2013, 2016) analyzed how the regulation of the old legacy network affected NGA adoption and coverage in 27 European Member States. Briglauer et al., (2016) show that, in the period 2004-2014, the higher access prices imposed on the old legacy infrastructure positively increased NGN investment and adoption, and reduced the gap in the retail prices of old and new technology-based broadband services. Grajek and Roller (2012) examined 70 operators in 20 European countries in the period 1996-2006 and show that access regulations lowered total industry and individual firms' investments.

A few papers have analyzed market entry in relation to unbundling regulations in the telecommunications market using data at the municipal level. First, a handful analyzed entry in the US telecommunications market prior to 2004, when the regulator removed unbundling obligations on fiber-optic premises so as to foster infrastructure competition and promote investment. For example, Greenstein and Mazzeo (2006) show that network element unbundling extended the variety of entrant operators after the 1996 Telecommunications Act, while Economides et al. (2008) found that the service-based competition promoted by unbundling reduced prices and increased service quality. Xiao and Orazem (2009), drawing on data at the zip code level in the US from 1999 to 2004, show that the first potential group of entrants in a local market may significantly delay their entry decision when facing the threat of additional entrants from neighboring markets. As a result, the first broadband providers, which do not face this entry threat, enjoy a certain degree of market power.

Second, Prieger et al., (2015) analyzed quality competition among internet service providers in California between 2011 and 2013. They examined how incumbent ADSL

⁵ Another strand in the literature uses aggregate country-level data to analyze broadband diffusion. Some papers discuss the relevance of inter- and intra-platform competition (Distaso et al., 2006; Lee and Brown, 2008; Bouckaert et al., 2010; Gruber and Koutroumpis, 2013; Briglauer, 2014; Ovington et al., 2017). Others use microdata to analyze broadband diffusion (Dauvin and Grzybowski, 2014; Nardotto et al., 2015).

⁶ Previous analyses of this approach can be found in Hazlett and Bazelon (2005) and Hausman and Sidak (2005).

firms respond to competition from entrant local exchange carriers and cable modem service providers. The paper shows that the firms' responses are heterogeneous to the type of provider and to the quality they offer. Incumbent local exchange carriers (ILECs) improved the quality of their ADSL offer when a cable operator entered the market, or when the incumbent cable operator improved its networks with DOCSIS 3.0. Yet, ILECs did not raise their ADSL service quality when competitive local exchange carriers (CLECs) only offered ADSL; however, they increased their speed when CLECs deployed fiber in the local market.

Third, Nardotto et al., (2015) examined LLU entry at the local exchange level in the United Kingdom in the period 2005-2009. They show that larger markets support a greater number of entrants, which confirms the importance of high fixed investment costs. Moreover, they find that entry is highly persistent over time, which implies that the technology is associated with substantial sunk costs. The authors then use the results of the entry model to study the determinants of broadband penetration and conclude that while LLU entry contributed to an increase in broadband penetration at the beginning of the period, cable competition had a greater impact at the end of the period. Their paper also shows that entrants invested in LLU in order to differentiate their services from those of the incumbent.

Our paper is closely related to recent studies that use microdata to examine the effects of unbundling on investment in NGA. Minamihashi (2012) analyzes the impact that the unbundling regulations imposed on the Japanese incumbent had on the entrants' NGN investments. Using municipal level data from 2005 to 2009, he shows that unbundling reduced the profits of cable television operators and prevented them from building their own fiber networks. In contrast, in the period analyzed, the incumbent's NGN investments were unaffected by this regulation. Fabritz and Falck (2013) use a panel dataset for exchange areas in the UK to analyze how local deregulation of wholesale broadband access affected investment. They find that in the deregulated areas local exchanges experienced a significant increase in the entry of LLU operators. Moreover, deregulation in these areas also increased the probability of the incumbent rolling out its FTTC infrastructure.

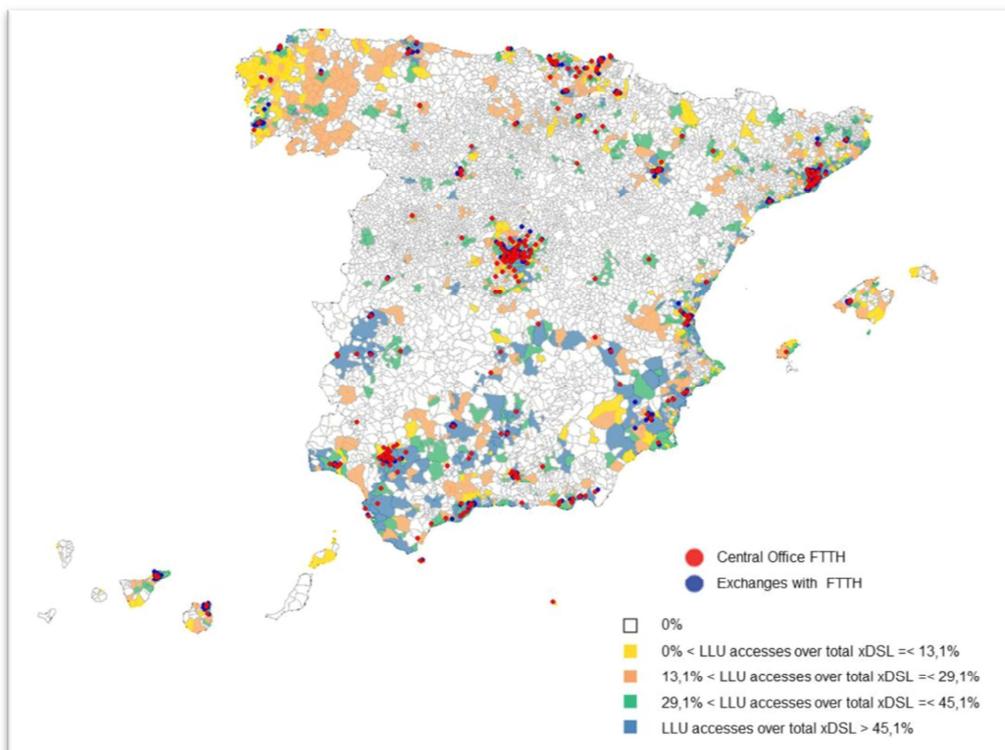
Finally, the paper that is closer to ours is Bourreau et al., (2017). Their study analyzes the incentives of French operators to deploy FTTH technology in different areas of the country. They use a detailed geographical dataset with information on the number of LLU competitors and the number of operators deploying fiber in 36,066 municipalities of France over the period 2010-2014. One important difference between this paper and ours is that, in the period analyzed, two entrants – SFR and Free – and the incumbent operator – Orange – simultaneously deployed their fiber networks. The situation described introduces a level of complexity in the strategies of the French operators that we do not encounter for the Spanish case where only Telefónica

invested. The authors conclude that the presence of LLU operators in local markets had a positive impact on the entry of the three fiber operators. On the one hand, SFR and Free always entered a local market via LLU first; on the other, investment by the three fiber operators was positively influenced by the presence of alternative LLU operators. The deployment of fiber enabled these operators to differentiate their offer from that of DSL-based services. The authors also show that the presence of cable operator Numericable's upgraded facilities stimulated fiber deployment by the other operators.

3. Broadband market and fiber deployment in Spain

The deployment of fiber networks in Spain was initiated in 2008 when Telefónica began rolling out its FTTH network in densely populated areas of the country, such as Barcelona and Madrid. Initial fiber investments focused on the trunk network, but quickly spread to the periphery with the deployment of fiber nodes that shortened the distance between the home connection and the core of the network. Figure 1 shows the local exchanges with FTTH deployment and the distribution of unbundled loops at the municipal level in 2013. An initial inspection suggests that Telefónica's deployment focused above all on highly populated areas and zones with a high penetration of unbundled local loops.

Figure 1: FTTH central offices and LLU penetration in Spain (2013)



Source: CNMC

To roll out fiber to the customers' homes, Telefónica used its civil works infrastructure: ducts, masts and other installations. Indeed, the availability of this civil infrastructure greatly favors FTTH investment, given that reaching the end customer is the most costly part of fiber roll-out⁷. In order to facilitate fiber roll-out, in 2009 the Spanish regulator (CNMC) obliged Telefónica to provide other operators with access to its ducts and civil infrastructure and applied a cost-oriented pricing system. This measure was taken to provide incentives for entrants to install their own fiber networks by using the incumbent's infrastructure. However, in the period analyzed no entrant took advantage of this possibility.

In order to deploy its fiber, Telefónica initially upgraded a number of local exchanges in the copper network, renamed FTTH central offices. Each one of these offices serves a much larger area than that served by a copper local exchange and requires fewer connections. This, coupled with the fact that the operating costs of fiber networks are lower than those of copper networks, provides an additional motivation for network replacement. By 2013, Telefónica's FTTH network comprised 283 FTTH central offices, capable of providing broadband services to an area that had previously been served by 636 copper local exchanges. The investment process was intense and in June of 2013, the last period available in our data set, 3.1% of Spanish municipalities (49.7% of the population) had access to FTTH technology. This figure is higher than that reported one year later for France, where coverage reached 1.6% (Bourreau et al., 2017).

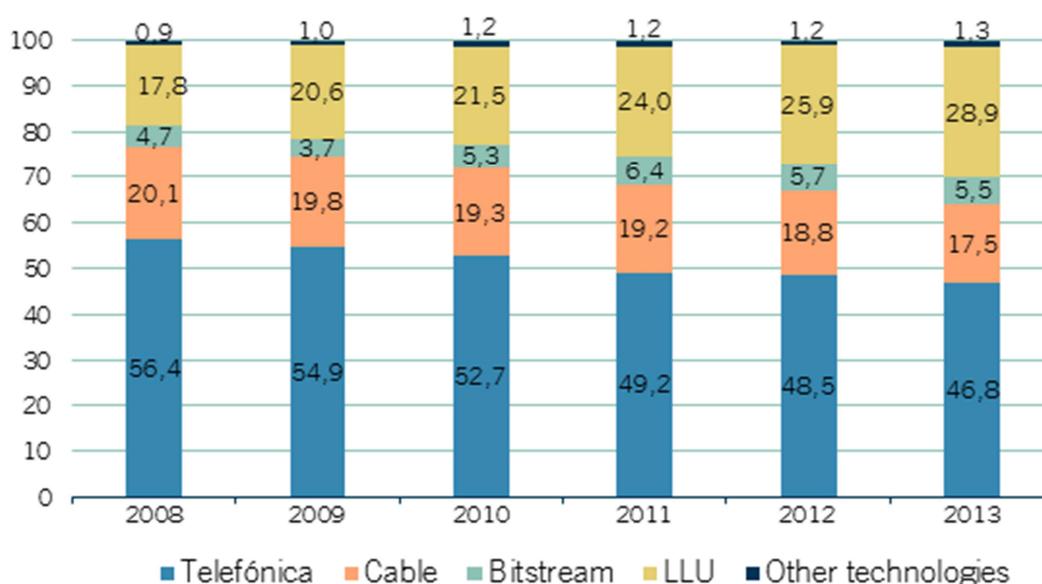
In the period 2009-2013, the Spanish broadband market underwent considerable expansion, growing from 9.1 million lines at the end of 2008 to 12.2 million lines in 2013. xDSL and cable technologies were the main technologies provided and they supported approximately 95% of retail broadband lines. In contrast, while in 2008 no FTTH connections had yet been installed, by December 2013 there were 626,000 lines in operation (that is, 5% of the total number of broadband lines). Other technologies (such as WiMAX) enjoyed very small market penetration.

In the period analyzed, regulatory obligations to provide wholesale fiber services had not yet been established in Spain; indeed, it was not until February 2016 that they would be introduced. During the period of analysis, wholesale bitstream services were capped at 30 Mbps and Telefónica's xDSL competitors' wholesale services were dependent on the legacy network: LLU and bitstream services.

Cable broadband was provided via proprietary networks that were built in the late 90s and which have not been expanded since. By 2010, these networks had been updated to the DOCSIS 3.0 standard and, therefore, during the period of analysis, cable operators were able to market high speed offers similar to those provided by FTTH.

⁷ According to BEREC (2016), civil infrastructure works can constitute up to 70-80% of the cost of deploying this technology.

Figure 2: Broadband market shares by access mode in Spain (percentages)



Source: CNMC

Figure 2 shows that between 2008 and 2013 there was a substantial increase in the market share of operators providing LLU services, at the expense of Telefónica and of the cable operators using proprietary networks. This can be explained in part by the differences in the prices charged by the operators. According to CNMC's annual reports, in this period the retail prices set by LLU operators were significantly lower than those of Telefónica and the cable operators. Moreover, LLU prices were considerably lower than those of bitstream, reflecting substantial differences in their respective wholesale tariffs (for example, in 2009, monthly rental of the local loop was fixed at 7.79 euros, whilst the main bitstream modalities costed around 16 euros per month).

4. Data

We examine Telefónica's deployment strategy using a semi-annual balanced panel dataset for the operator's FTTH deployment in 6,063 Spanish municipalities from the first semester of 2010 to the first semester of 2013 (a total of seven time periods). As explained above, during the period examined Telefónica was the only operator undertaking FTTH investment activity of any relevance in Spain.

The 6,063 municipalities included in the analysis had at least one fixed active broadband connection in 2010 provided by any one of Spain's main telecom

operators⁸ and by means of xDSL (copper) or cable broadband technologies. In 2010 these municipalities accounted for 99.2% of the Spanish population.

Our analysis draws on a data set collected and compiled by the *Comisión Nacional de los Mercados y la Competencia* (CNMC), the Spanish agency responsible for the economic regulation of the telecommunication sector. The database provides information on Telefónica's fiber deployment and on the number of broadband subscribers by technology and access mode in each local market (this is, xDSL and cable customers as well as the number of commercialized LLU and bitstream lines).

When operators consider rolling out an NGA network in a new municipality, they take into account both the deployment costs and the expected revenues that the legacy and new technologies will generate. The latter depend on the market demographics and the presence and strength of their competitors. To analyze Telefónica's investment decision, the main variable of interest here is *Fiber deployment*, capturing whether Telefónica has deployed FTTH in a municipality. This variable takes a value of 1 when the operator has deployed at least one connection in the municipality and zero otherwise.

We measure the competitive pressure that Telefónica faces at the municipal level by computing the cable, LLU and bitstream market shares. We exclude from the analysis other broadband technologies, including WiMAX, which are much less common in the Spanish market. The variables *Cable*, *Local Loop* (LLU) and *Bitstream* are included in the empirical models with a lag.

The database is completed with municipal-level sociodemographic data from the Spanish National Statistical Office (INE) and the Spanish Public State Employment Service (SEPE). Specifically, we consider a group of variables that reflect the size of the market as well as the operators' deployment costs at the municipality level. The variable *Real estate units* is the sum of households, premises and offices in the municipality and is included in the model in logs. Since this variable is only available for 2011 and 2012, we impute its value for the other periods by using the closest time value. The variable population *Density* is introduced in the model in logs, and reflects the importance of density economies in Telefónica's investment strategy. The density of population is related to the costs of fiber deployment as FTTH is more easily deployed in urban areas with tall buildings and with a wide availability of ducts (civil engineering and construction costs are lower in urban areas). *Elderly population* is the percentage of the population in the municipality aged 65 years old or more, and *Unemployment* is the percentage of the population aged 20 to 64 seeking a job according to the SEPE. This last variable is included in the models as a proxy of the consumers' income and willingness to pay for the FTTH service.

⁸ These were Telefónica, Vodafone, Jazztel, Orange, Ono, R, Telecable and Euskaltel. At the start of the period of analysis in 2010, these operators accounted for 97.5% of the national broadband market.

All the datasets were merged using a unique municipality INE code. Table 1 provides summary statistics for all the variables used in the empirical models.

Table 1. Descriptive Statistics (all periods)

| | Observations | Mean | Standard deviation | Min | Max |
|--------------------|--------------|-----------|--------------------|-------|------------|
| Fiber deployment | 42,441 | 0.022 | 0.146 | 0 | 1 |
| LLU | 42,441 | 0.048 | 0.111 | 0 | 0.673 |
| Bitstream | 42,441 | 0.123 | 0.081 | 0 | 0.569 |
| Cable | 42,441 | 0.031 | 0.112 | 0 | 0.872 |
| Unemployment | 42,441 | 0.118 | 0.058 | 0 | 0.585 |
| Elderly population | 42,441 | 0.250 | 0.103 | 0.034 | 0.744 |
| Real estate units | 42,441 | 4,695.701 | 31,737.430 | 17 | 1,861,334 |
| Density | 42,441 | 232.087 | 1,029.198 | 0.380 | 24,705.240 |

5. Empirical strategy

Our model of Telefónica’s FTTH deployment in a municipality is based on Bresnahan-Reiss (1991), where demand is stochastic and the incumbent’s decision to enter a municipality or not depends on whether the profits from entry exceed their costs. In our case, entry costs are mainly local and determined by the cost of deploying the fiber, which depends on such characteristics as the degree of urbanization and the urban planning rules operating in each municipality⁹. On the other hand, Telefónica’s profits from rolling out the new technology depend on the type of competition that it faces in each municipality. Taking this information into account, we identify the incumbent’s FTTH deployment strategy by fitting logit regression models for which the dependent variable is *Fiber deployment*.

Several limitations of our balanced dataset preclude the use of a fixed effects model. One advantage of this estimation strategy is that it is not biased because of omitted time-invariant variables. However, it cannot be used to uncover time-invariant causes of the dependent variable and it cannot properly identify the coefficients of variables that do not vary significantly over time. Additionally, in the case of logit fixed effects models, the municipalities with a constant dependent variable over the follow-up period cannot be included in the analysis (Suárez and García-Mariñoso, 2013). Unfortunately, in our study, these two common drawbacks of a fixed effects approach

⁹ Since we do not observe fiber exits, we are unable to identify sunk entry costs by comparing entry and exit thresholds, as in Bresnahan-Reiss (1994). A similar model has been used to examine LLU entry and exit decisions by Xiao and Orazem (2011) and Nardotto et al., (2015).

are present. First, the variation shown by our competition and sociodemographic explanatory variables over time is very limited due to the short study span. And second, as the overall rate of Telefónica FTTH deployment at the municipal level was low in the first semester of 2013, a logit fixed effects regression model would overlook more than 95% of the sample observations, thus dramatically reducing the power of the analysis.

Therefore, we consider logit regressions with random effects. This model can be expressed as follows:

$$\log\left(\frac{\Pr[Y_{i,t+1} = 1 \mid X_{i,t}, \beta, \alpha_i]}{1 - \Pr[Y_{i,t+1} = 1 \mid X_{i,t}, \beta, \alpha_i]}\right) = X'_{i,t}\beta + \alpha_i$$

where, Y is the binary fiber deployment in municipality i at time $t+1$, X is the set of covariates measured at time t , β the associated coefficients to be estimated and α_i the random effect following a normal distribution with mean equal to zero.

To avoid potential endogeneities due to reverse causality all the covariates are lagged. Specifically, the competition variables (*LLU*, *Bitstream* and *Cable*) are lagged one period (six months) and the sociodemographic variables are lagged two periods (recall that half-year data are not available for these variables). Moreover, by lagging the covariates, we are “mimicking” the information set that Telefónica held when taking its strategic decisions of where to roll out FTTH, given that those were based on the latest information available before initiating deployment. A time variable is included in all the specifications to control for the increasing trend in FTTH deployment over time and an interaction between population density and the time trend is also used.

Finally, to deal with potential municipality fixed specific effects, without relying on the within municipality variation of the fixed effects models, we followed Ovington et al., (2017) and re-fitted our models including the Spanish regions (17 groups) as covariates.

6. Results

This section examines how local market competition and the sociodemographic characteristics of the municipalities affected Telefónica’s decision to deploy fiber. Recall that Telefónica was competing with cable operators and with other operators that relied on various regulated wholesale services to access their consumers. Taking this into account, we differentiate between three local competition categories, which

differ in terms of the operator's reliance on the incumbent's network: *Cable*, *LLU* and *Bitstream*.

Table 2 reports the estimation results for four logit random effects models. In all the models, the dependent variable is fiber deployment, which takes a value of 1 for those periods and municipalities for which there is at least one fiber deployment and 0 otherwise. Moreover, all models include the lagged competition and sociodemographic variables as explanatory variables. Model 1 does not include the regional dummies whilst Model 2 does.

Note that many of the Spanish municipalities are extremely small, making them very unattractive investment objectives. Hence, for robustness, Models 3 and 4 are the re-fits of Models 1 and 2, respectively, excluding municipalities with less than 1,000 inhabitants. Although sample size in Models 3 and 4 is reduced by almost 50%, the results are highly consistent with those obtained when using all the municipalities.

We first consider the impact that the presence of the different types of competitor had on Telefónica's investment strategy. Table 2 shows that the effect of local loop unbundling on Telefónica FTTH deployment was positive and statistically significant in all the models. Thus, as the market share of LLU competitors increased by 1%, the probability of fiber deployment in the municipality grew by 12-14%¹⁰. It should be stressed at this juncture that this type of operator had been Telefónica's fiercest competitors since the liberalization of the market at the end of the nineties, and that they managed to attract a large number of customers thanks to their low prices and differentiated service. However, in this period, xDSL operators did not develop their own fiber networks. Additionally, there were no wholesale services (regulated or otherwise) supporting an indirect mechanism for the provision of high quality end services. In the best case, existing wholesale services based on the copper network were only able to support broadband offers with a maximum speed of 30 Mbps, which is much slower than the speeds that can be provided with NGA networks. Thus, by deploying FTTH in areas in which LLU was more prevalent, Telefónica managed to differentiate its offer from those of its xDSL competitors and to make some profits from its NGA investment. Note also that the wholesale revenues foregone by Telefónica for each new FTTH client that switched from an LLU competitor were relatively small, as the local loop tariff was low.

¹⁰ Note that as the probability of fiber deployment (P_i) is so low, the odds are similar to the probability and the odds ratio is similar to the probability ratio.

Table 2. Logit random-effects regression results for Telefónica's fiber deployment in local markets

| | Model 1 | Model 2 | Model 3 | Model 4 |
|-------------------------|-------------------------|------------------------|-------------------------|-------------------------|
| LLU | 11.426*** (2.557) | 13.243*** (3.085) | 10.982*** (2.913) | 11.833*** (3.515) |
| Bitstream | -19.556*** (6.925) | -16.886** (7.368) | -19.797*** (7.607) | -18.913** (8.538) |
| Cable | 7.853*** (2.659) | 5.217 (3.266) | 8.495*** (2.868) | 3.431 (4.164) |
| Unemployment | -35.941*** (9.046) | -35.151*** (11.066) | -25.566*** (9.927) | -26.601** (12.038) |
| Elderly population | -103.311*** (10.266) | -98.758*** (11.945) | -111.851*** (11.618) | -117.911*** (14.857) |
| Log Real estate units | 4.913*** (0.381) | 5.949*** (0.444) | 5.673*** (0.423) | 7.408*** (0.514) |
| Log Density | 3.985*** (0.780) | 5.587*** (0.819) | 3.946*** (0.796) | 5.734*** (0.901) |
| Log Density * Dec 2010 | -1.314* (0.694) | -1.477** (0.737) | -1.353* (0.729) | -1.573* (0.812) |
| Log Density * June 2011 | -2.642*** (0.726) | -3.121*** (0.777) | -2.606*** (0.760) | -3.161*** (0.830) |
| Log Density * Dec 2011 | -3.055*** (0.725) | -3.727*** (0.770) | -2.920*** (0.767) | -3.625*** (0.833) |
| Log Density * June 2012 | -3.149*** (0.729) | -3.821*** (0.769) | -3.052*** (0.776) | -3.816*** (0.845) |
| Log Density * Dec 2012 | -3.432*** (0.735) | -4.151*** (0.771) | -3.334*** (0.782) | -4.194*** (0.849) |
| Log Density * June 2013 | -3.027*** (0.741) | -3.726*** (0.776) | -2.936*** (0.787) | -3.778*** (0.856) |
| December 2010 | 11.397** (5.286) | 12.807** (5.648) | 11.735** (5.536) | 13.682** (6.159) |
| June 2011 | 25.745*** (5.609) | 29.797*** (6.047) | 25.341*** (5.859) | 30.398*** (6.386) |
| December 2011 | 32.923*** (5.633) | 38.768*** (6.057) | 31.970*** (5.915) | 38.834*** (6.380) |
| June 2012 | 37.090*** (5.646) | 43.145*** (6.065) | 36.392*** (5.976) | 44.138*** (6.440) |
| December 2012 | 41.190*** (5.665) | 47.805*** (6.066) | 40.551*** (5.995) | 49.331*** (6.429) |
| June 2013 | 40.932*** (5.678) | 47.628*** (6.103) | 40.304*** (6.020) | 49.370*** (6.457) |
| Regional dummies | NO | YES | NO | YES |
| Sigma | 11.723 | 12.450 | 11.825 | 13.241 |
| Observations | 42,441 | 42,441 | 22,491 | 22,491 |

*** Significant at 1%. ** Significant at 5%. *Significant at 10%*. Standard errors in parentheses.

In contrast, the effect of bitstream competition on fiber deployment is negative and statistically significant in all models. A 1% increase in the market share of bitstream operators results in a 16-18% reduction in the probability of fiber deployment. Entrants to Spain's telecommunications markets had few options to compete aggressively with Telefónica when using copper-based bitstream wholesale services. The reason for this is two-fold: on the one hand, bitstream gave them little room to differentiate their product¹¹; and on the other, their services had to be marketed at higher retail prices because bitstream wholesale prices were relatively high compared to LLU. The fact that competition was weaker in these municipalities and that Telefónica obtained larger wholesale revenues from its competitors reduced the incumbents' incentives to roll-out fiber. In summary, compared to LLU, the additional rents that the company could obtain as a result of service differentiation were smaller and the wholesale revenue reduction was larger.

Evidence regarding cable competition is not as conclusive as that for LLU and bitstream. Models 1 and 3 show that the cable market share has a positive and statistically significant effect on fiber deployment, suggesting that Telefónica invested in this technology in municipalities where competition from cable operators was intensive. Yet, when we include regional effects in Models 2 and 4, we no longer find a statistically significant association between Telefónica's fiber deployment and the cable market share, although in Model 2 the coefficient is almost significant at the 10% level (p-value of 0.110). Additionally, the positive effect of cable on fiber deployment is smaller than that of LLU in all models. Clearly, fiber roll-out was used as a product differentiation mechanism in the face of competition from LLU entrants, whilst this differentiation effect appears as less marked in the case of the stronger presence of cable companies.

Interestingly, the results of our empirical model are similar to those obtained by Bourreau et al., (2017) in France, where the authors report a positive and significant effect of both the number of LLU entrants in a municipality on fiber deployment and the presence of the French cable operator on fiber roll-out. However, they do not provide any results regarding the effects of bitstream on fiber deployment. However, our results contrast with those of Briglauer et al., (2013), who report a negative joint impact of LLU and bitstream on fiber deployment. This paper, though, uses EU-national level data and does not distinguish between the individual effects of LLU and bitstream. One novelty of our paper is that we are able to examine the separate

¹¹ The main difference between LLU and bitstream access is the provisioning of one of the main network elements, namely the digital subscriber line access multiplexer or DSLAM. In the case of LLU, the DSLAM is always operated by the new market entrant, whereas in the case of bitstream access, the DSLAM is operated by the incumbent. As the incumbent operates the DSLAM, the new entrant is technically unable to alter the xDSL access link (towards the customer) and, so, opportunities for service differentiation are reduced.

effects of these two competition modes, and we find that they generate opposite effects¹².

Finally, turning to the sociodemographic characteristic of the municipalities, we observe that all the coefficients of the variables included in the four models have the expected sign and are strongly significant. Market size, measured by the logarithm of the number of households and offices in the municipality, has a positive effect on fiber deployment. Similarly, the coefficient of the variable Log Density is positive and statistically significant and the negative and increasing coefficients of the interaction between density and time show that with time Telefónica is more likely to roll-out fiber in less densely populated areas.

These two results confirm the relevance of scale in the deployment of FTTH, and are essential for identifying the municipalities in which the public authorities need to intervene to guarantee the development of the service.

Unemployment is included in the model as a proxy for income and willingness to pay. The results show that as the level of unemployment increases, the probability of fiber deployment in a municipality diminishes substantially. Thus, in the models, a 1% increase in the unemployment rate results in a 23-30% reduction in the probability of fiber deployment. Finally, the variable *Elderly population*, which reports the lagged value of the proportion of population aged 65 or more, has a negative and statistically significant impact on the deployment of fiber. As reported in previous studies of the digital divide in Spain, the elderly are the segment of population least likely to adopt new technologies due to such factors as learning and physical obstacles (García-Mariñoso and Suárez, 2013). In line with these reports, we find that in municipalities with a greater proportion of elderly inhabitants, Telefónica was less likely to invest in fiber deployment.

7. Conclusion

This paper has analyzed the fiber deployment undertaken by Telefónica in Spain between 2010 and 2013, a period in which the incumbent was the only operator in the country to invest in this technology. Our first contribution has been to show that the regulation of access to Telefónica's legacy and NGA networks has played an especially relevant role in the operator's investment strategy. During this period, Telefónica focused its investment in those municipalities in which LLU competition was most

¹²Another difference between our analysis and studies based on data from various countries is that, as we focus on one specific country, our LLU and bitstream coefficients isolate competition effects and do not reflect any regulatory variations.

intense and, to a lesser extent, in those in which cable operators enjoyed a large presence. In contrast, the firm's level of investment was comparatively smaller in municipalities with bitstream entry. These findings suggest that Telefónica's strategy for deploying fiber was mainly influenced by i) the objective of differentiating its offer from those of its competitors; ii) the intensity of competition of the different access modes; and, iii) the wholesale revenues foregone as a consequence of its investments.

LLU competition provided a strong initial incentive for fiber deployment. In the wake of the intensive investment episode studied here, Telefónica's competitors began to deploy their own fiber networks, often by means of co-investment plans with each other or with Telefónica. As a result, by December 2016, the number of FTTH accesses deployed had almost increased eightfold since June 2013. All of Spain's leading operators have contributed to this process and by the end of 2016 Telefónica's market share of FTTH access lines stood at 61.4%. Within Europe, Spain is the country with the third largest FTTH coverage, with 63% of households covered by July 2016, compared to a mean figure for the EU of 24%¹³. Our second contribution has been to show how the sociodemographic characteristics of the municipalities affect Telefónica's investment decisions. We have shown that market size and the density of population have a positive effect on fiber deployment, whilst the level of unemployment and the percentage of elderly population have a negative effect. In the context of a liberalized market, the adoption of a new technology by private operators will clearly depend on the profitability of the investment. This is an aspect that needs to be accounted for in the future design of the regulatory model for the telecommunications sector.

In 2016, the Spanish authority modified sector regulation in recognition of the different levels of competition at the municipal level. In its review of broadband wholesale markets, the CNMC introduced separate geographical remedies. Thus, 66 municipalities were designated as "competitive" as regards their NGA networks, being served by at least three operators, each providing a minimum of 20% local coverage. In these municipalities, the CNMC deemed it unnecessary to regulate residential NGA wholesale services. In contrast, in the "non-competitive" municipalities, Telefónica was required to offer a virtual access service to its FTTH accesses, and an indirect wholesale access service was established to its fiber network¹⁴. In the coming years, it will be extremely important to study the impact of these interventions on fiber deployment and competition.

In 2016, the European Commission, aware of the risks resulting from insufficient investment in the sector, also proposed introducing a new Directive to establish a European Electronic Communications Code. This includes several proposals aimed at

¹³ For the FTTH market share, see CNMC's quarterly data at data.cnmc.es. The source for the household coverage is the EC's Europe's Digital Progress Report, 2016.

¹⁴ This reform eliminated the 30 Mbps limit for access to Telefónica's network.

boosting investment in high capacity networks. For example, the Directive outlines a route for unregulated network expansions when those are based on co-investment agreements and for the removal of the regulation of wholesale offers of vertically separated companies. The current debate is whether such regulatory forbearance may have a detrimental impact on competition in the sector. Indeed, this is a key issue, as our results show that competition and product differentiation are essential to spur network investment.

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