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## Unbundling the Incumbent and Entry into Fiber: Evidence from France

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# Unbundling the Incumbent and Entry into Fiber: Evidence from France

## Abstract

We use panel data on 36,104 municipalities in metropolitan France over the period 2010-2014 to estimate two models of entry into local markets by: (i) alternative operators using wholesale access to the legacy copper network via local loop unbundling (LLU), and (ii) the incumbent and two alternative operators using the fiber technology. We find that a higher number of LLU competitors, and hence a less concentrated local market, has a positive impact on entry by fiber operators. Moreover, the presence of upgraded cable network in the local municipality stimulates fiber deployment. However, firms may choose to upgrade copper lines instead of investing in fiber networks. We use the estimates to calculate entry thresholds into local markets, which are substantially lower for broadband provision via LLU than via fiber and decrease over time. Fiber deployment becomes cheaper over time, but according to our estimates it will remain unprofitable for the vast majority of municipalities in France within the next years.

JEL-Codes: K230, L130, L510, L960.

Keywords: fiber broadband, local loop unbundling, market entry.

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# 1 Introduction

Universal access to superfast broadband is on top of the public policy agenda in the European Union. The roll-out of fiber-optic networks delivering superfast broadband access to the Internet – the so-called next-generation access networks – is expected to improve productivity and stimulate growth and job creations.<sup>1</sup> The European Commission has thus set as a target in its Digital Agenda that half of European households should have the ability to access the Internet at speeds of 100 Mbps or more by 2020.<sup>2</sup> In September 2016, the Commission further announced that by 2025 all European households should have access to connections with speeds of at least 100 Mbps.<sup>3</sup>

The roll-out costs of next generation access networks are, however, significant. For example, the European Commission estimates that it would cost between €181 and €268 billion to achieve its 2020 objectives.<sup>4</sup> Private operators deploying fiber also face competition in many local markets from DSL and cable operators, offering basic and fast broadband services to consumers.

The contribution of this paper is to analyze how competition in local broadband markets impacts investments in the new fiber infrastructures. To the best of our knowledge, this is the first paper which at a granular local level analyzes the deployment of fiber infrastructures and the impact of legacy broadband networks on the deployment of next generation access infrastructures. Our results shed light on the ongoing debate on the impact of competition on investment in telecommunications infrastructures.

The telecommunications industry has been subject to regulation since the opening to competition in the 1990's, to limit the exercise of market power by incumbent operators and allow competition to emerge. In particular, to foster entry and competition in the broadband market, the European Commission has implemented in the early 2000's wholesale access to the incumbents' local networks, a regulatory policy known as "local loop unbundling" (or LLU). LLU requires incumbents to grant access to their physical local copper infrastructure, at regulated

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<sup>1</sup>See Röller and Waverman (2001), Czernich et al. (2011) and Ahlfeldt et al. (2017), among others, for empirical evidence on the impact of telecommunications infrastructures, and in particular broadband infrastructures, on growth and jobs.

<sup>2</sup>"A Digital Agenda for Europe," European Commission, COM(2010) 245.

<sup>3</sup>Source: "State of the Union 2016: Towards a Better Europe - A Europe that Protects, Empowers and Defends."

<sup>4</sup>See "European Broadband: investing in digitally driven growth," European Commission, COM(2010) 472.

prices, to enable entrants to provide DSL (“digital subscriber line”) broadband services. The introduction of LLU led to a wave of entry in local markets by new entrants.

In the context of next generation access networks, operators now face an investment challenge. The incentives of operators to roll out fiber infrastructures are affected in particular by the competitive conditions in local broadband markets. An important question for policymakers is then whether there is a trade-off between competition in broadband markets and investment in fiber networks. Even though this question is critical for both policymakers and academics, so far there exists only very limited empirical evidence on the impact of competition in broadband markets on operators’ incentives to deploy fiber networks.

In this paper, we analyze the impact of competition on fiber investments using data on municipalities in metropolitan France.<sup>5</sup> The French market is interesting for our analysis for the following reasons. First, the regulation of wholesale broadband access via LLU in France has promoted entry and competition since the early 2000’s. Second, in the past few years fiber broadband has been deployed not only by the former telecommunications incumbent Orange, but also by its two main rivals, SFR and Free. Third, there is a single cable network operator, Numericable, which has been upgrading its network to a hybrid fiber-coaxial architecture, allowing for Internet speeds comparable to fiber. Fourth, since 2013 Orange and other DSL operators have been upgrading their broadband networks to offer VDSL services, which can provide Internet speeds up to 50 Mbps to some consumers.<sup>6</sup>

We use panel data on 36,104 municipalities in metropolitan France over the period 2010-2014 to estimate two models of entry into local markets by: (i) operators using LLU to deliver basic broadband services; and (ii) the incumbent and two other DSL operators using the fiber technology to offer fast broadband services. In the model of fiber entry, we allow the entry decision to depend on the local market presence of competing LLU operators. We also consider the impact of the local market presence of the upgraded cable modem and VDSL technologies. When estimating the models, we take into account the role of local market characteristics such as

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<sup>5</sup>The incentives to invest in fiber networks are also affected by the regulatory environment. However, we are not able to identify the impact of regulation (in particular, access regulation) on investments in fiber, due to a lack of geographical variation in LLU access prices. Our focus is therefore on the impact of competition at the local level on investment incentives.

<sup>6</sup>The highest speed achievable with a DSL connection is 8 Mbps. VDSL provides higher speeds, between 8 Mbps and 50 Mbps, depending on the length of the consumer’s copper line.

market size, population density and income, and of the heterogeneity in local market conditions.

We find that the number of LLU competitors in a local market has a positive impact on entry by fiber operators. In other words, competition in the DSL market stimulates investment. In the data we observe that the fiber entrants SFR and Free always enter a local market via LLU first. However, our estimation results show that the decision to deploy fiber by the incumbent Orange and the alternative operators SFR and Free is also positively influenced by the presence of other LLU operators. Based on a theoretical framework (developed in the appendix of the paper), our interpretation is that, because of the vertical differentiation between basic and fast broadband, a higher number of LLU competitors reduces less the profits derived from new fiber infrastructures than the opportunity cost of investment due to lost DSL profits.

Moreover, the availability of upgraded cable in the municipality stimulates fiber deployment. Fiber entrants may benefit from investment spillovers, which reduce the cost of rolling-out fiber when upgraded cable is present. DSL operators deploying fiber may also try to avoid being preempted by the cable operator Numericable for the delivery of fast broadband services to consumers. Finally, we find that the deployment of the VDSL technology slows down fiber deployment. Operators may choose to upgrade their DSL network to VDSL instead of investing in a fiber network. An upgrade of LLU competitors to VDSL thus reduces the profit incentive from fiber deployment.

We also compute the threshold size of a municipality to accommodate LLU and/or fiber entry. We find that entry thresholds for LLU are substantially smaller than for fiber, which reflects the much smaller scale of investment required for LLU. Using our estimates, we predict that about 55% of the population in France will be covered by fiber by 2020 and 78% by 2025, which falls short of the new objective of full coverage of the European Commission.

The remainder of the paper is organized as follows. In Section 2, we review the relevant theoretical and empirical literature. In Section 3, we provide some background on the broadband industry in France. Section 4 presents the data. In Section 5, we introduce the econometric framework, and in Section 6 we present the estimation results. Finally, Section 7 concludes.

## 2 Literature Review

### 2.1 Theory

Bourreau, Cambini and Dogan (2012) and Inderst and Peitz (2012) analyze the effect of access to the legacy copper network (i.e., local loop unbundling) on the incentives to deploy a fiber network for an incumbent and an entrant operator. They show that access affects both the pre- and post-investment profits, and hence, influences investment incentives through different channels.<sup>7</sup> As a consequence, a lower access price for copper implies less investment incentives for the entrant, and more or less investment incentives for the incumbent.

Bourreau et al. (2012) and Inderst and Peitz (2012) take market structure (a duopoly) as given, and analyze the effect of access regulation on investment. By contrast, we analyze the impact of the market structure of local markets on investment. Our paper is thus also related to the broad literature on the impact of market structure on investment or innovation.<sup>8</sup> In particular, Yi (1999) and Belleflamme and Vergari (2011) study how the profit incentive, defined as the difference between post- and pre-investment profits, varies with the number of firms in the market. Yi (1999) considers a homogeneous product market under Cournot competition, and shows that the profit incentive decreases with the number of firms for a large class of demand functions. Belleflamme and Vergari (2011) consider an oligopoly with horizontally differentiated products and show that the relation between the profit incentive and the number of firms can be non-monotonic.

More recently, Motta and Tarantino (2017) have proposed a general framework to study the impact of a merger on investment, and shown that a merger tends to reduce total investment, absent any efficiency gains.<sup>9</sup> Their results therefore suggest a positive effect of entry on investments.

We contribute to this literature by providing empirical evidence on the impact of local market structure and entry on investments in the telecommunications sector.

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<sup>7</sup>Bourreau et al. (2012) show that three different effects are at play: (i) a replacement effect for the entrant; (ii) a wholesale revenue effect for the incumbent, due to lost access revenues when migrating to fiber; and (iii) a business migration effect that affects both firms, which is due to the fact that a low access price leads to low prices for broadband services, and hence a low profitability for fiber investments.

<sup>8</sup>See Gilbert (2006) for a survey of the theoretical and empirical literature on this topic.

<sup>9</sup>In a related work, Federico, Langus and Valletti (2017) show that a merger reduces innovation efforts.



## 2.2 Empirics

Our paper is related to three streams of empirical literature, which study: (i) investments in next-generation fiber networks, (ii) the quality competition between Internet service providers, and (iii) entry into telecommunications markets.

The literature on investment in next-generation access (NGA) fiber networks is rather scant.<sup>10</sup> Some studies have analyzed the effect of access regulation on the migration from copper to fiber networks (see, e.g., Bacache et al., 2014; Briglauer, 2015; Briglauer, Cambini and Grajek, 2017). In particular, Briglauer et al. (2017) use data on incumbent telecom operators and cable players for 27 European member states for the period 2004-2014, and show that more stringent regulation of access to legacy or fiber networks harms investment by incumbent telecom operators. These studies however use country-level data and therefore cannot account for the strong within-country differences in fiber investments that we observe in our micro-level data.

There are only two recent papers which use local market data as we do. Minamihashi (2012) uses municipality-level data for Japan in years 2005-2009 and finds that the local loop unbundling (LLU) regulation imposed on the Japanese incumbent operator has prevented entrants from deploying new broadband infrastructures. According to his counter-factual exercise, LLU regulation led to a 24% decrease in the roll-out of new fiber infrastructures. However, the incumbent's NGA investments were not hindered by the LLU regulation. Fabritz and Falck (2013) use data on local exchange areas in the UK for the years 2007-2013 to analyze how the introduction of geographically differentiated regulation of wholesale broadband access has influenced investment in NGA networks by the incumbent. They find that deregulation had a positive effect on the roll-out of fiber.

These different papers study the impact of regulation on investment, whereas our focus is on the impact of market structure and competition at the local level on investment in next-generation fiber networks. To the best of our knowledge, we are the first to analyze this question.

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<sup>10</sup>By contrast, many studies have analyzed the impact of competition on the diffusion of the first generation of broadband, using cross-country data (see, e.g., Distaso, Lupi and Manenti (2006), and Bouckaert, Dijk and Verboven (2010)). Genakos, Valletti and Verboven (2017) also study the impact of mergers on prices and investment in the mobile market, and show that mergers increase investments by operators.

Our paper is also related to a recent stream of literature on quality competition between Internet Service Providers. Nardotto, Valletti and Verboven (2015) show that LLU entry had a positive impact on the quality of Internet services provided by entrants (i.e., the speed) in the UK, because of their efforts to differentiate from the incumbent. Prieger, Malnor and Savage (2015) study how DSL firms respond to competition in terms of quality of broadband (i.e., download speed) in a thousand local markets in California in years 2011-2013. They show that incumbent DSL firms increase the quality of their DSL products when a cable operator enters a local market and starts offering fast broadband, or when a competing operator deploys fiber in the market. In a similar vein, Molnar and Savage (2017) show that competition has a positive effect on speed. Based on data for about 5,500 households in the US, they analyze the relationship between market structure and product quality, and show that the speed is higher in markets with two or more competing firms, compared to markets with a single firm. Similar to these studies, we investigate how competition in a local market affects incentives to deploy fiber and offer higher-quality broadband services.

Finally, our paper is related to the literature on entry into telecommunications markets.<sup>11</sup> Most of the studies on entry into local telecommunications focus on the US market before the Federal Communications Commission (FCC) changed its decision on open access policy in 2004 (see Greenstein and Mazzeo, 2006; Economides, Seim and Viard, 2008; Xiao and Orazem, 2009 and 2011; Goldfarb and Xiao, 2011). In a more recent study, Nardotto et al. (2015) study the deployment of the broadband technology in years 2005-2009 in the UK. However, they do not observe entry in fast or ultrafast broadband (fiber) in their period of analysis, which is our main focus in the present paper.

### 3 Broadband Market in France

Broadband connections provide consumers with high-speed access to the Internet.<sup>12</sup> In France, four main wireline technologies are used to deliver broadband: digital subscriber line (DSL),

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<sup>11</sup>The literature on entry is mature and reviewed by Berry and Reiss (2007).

<sup>12</sup>The European Commission defines broadband as Internet connections with speed of at least 144 kbps. Basic broadband is defined as a connection with download speed below 30Mbps, fast broadband as a connection of 30Mbps or above, and superfast broadband as a connection of 100Mbps or above.

cable modem, very-high-bit-rate digital subscriber line (VDSL), and optical fiber. In 2014, DSL represented 88% of all broadband connections (with some of these connections being VDSL), cable modem 6.6%, and optical fiber 3.6%.<sup>13</sup>

DSL is a family of technologies used to transmit data over the traditional copper telephone wires, which connect customer premises to the main distribution frames (MDFs) of the historical operator (France Telecom/Orange in France). To provide DSL services to consumers, an operator builds a backhaul network down to the MDFs, and then installs DSL equipments in the MDFs to deliver high-speed Internet over copper lines. The asymmetric version of the DSL technology ('ADSL') was first introduced in France in 1999 by Orange. To allow entry and competition in the broadband market, the French regulator ARCEP quickly mandated Orange to provide access to its MDFs and copper lines to competitors, a policy known as 'Local Loop Unbundling' or LLU.<sup>14</sup>

This regulation led to a wave of entry of operators in local municipalities via LLU. Table B.1 shows the number of municipalities in which different operators have LLU presence. Free and SFR are the most active LLU operators, and therefore the main competitors to Orange in the DSL market, with a presence in 19,488 and 14,140 municipalities, respectively, as of 2014. There is also a competitive fringe of smaller LLU operators with presence in 8,610 municipalities as of 2014.<sup>15</sup>

Cable modem is a technology allowing to provide broadband over the coaxial cables originally developed to carry television signals. There is only one cable operator in France, Numericable, which covers about 30% of the population, mostly in urban areas. Since 2007, Numericable started to upgrade its cable network using the DOCSIS 3.0 standard, a hybrid fiber-coax technology which can deliver speeds exceeding by far those of DSL connections. Since then,

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<sup>13</sup>Other broadband technologies such as WiFi or satellite represented only 1.8% of broadband connections in 2014. Source: ARCEP observatory - High and very-high speed Internet - Retail market.

<sup>14</sup>Discussions between Orange and the regulator about LLU started in December 1999, and LLU experiments were launched in July 2000. In December 2000, the European Commission published its Regulation No. 2887/2000 on unbundled access to the local loop.

<sup>15</sup>The two next largest LLU operators are Axione (2,236 municipalities covered with LLU) and Bouygues Telecom (2,070 municipalities covered with LLU). The other LLU operators have mainly a regional presence and include Teloise, Moselle Telecom, Manche Telecom, Iris 64, Alsace Connexia, Medialys, Ovh, Armor Connectique, Hérault Telecom, Ariège Telecom, Haut Rhin Telecom, Colt, Rennes Metropole Telecom, Alliance Connectic and a number of other very small operators.

Numericable has not deployed cable infrastructures in new municipalities, which were not covered before 2007. Between 2010 and 2014, the period of our data, Numericable upgraded its cable network in 866 municipalities and the total number of municipalities with upgraded cable reached 1,068 in 2014 (see Table B.2). In October 2014, the French Competition Authority cleared the acquisition by Numericable of SFR, the third largest DSL player and second largest fiber operator.

VDSL is a specific DSL technology providing faster transmission speeds than standard DSL, but only for very short copper lines.<sup>16</sup> The deployment of VDSL has been authorized by the French regulator, ARCEP, in October 2013.<sup>17</sup> VDSL is deployed by the main DSL operators, Orange, Free and SFR. According to our data, as of 2014, in 22% of municipalities there was at least one active VDSL connection by one of the operators.

Finally, optical fiber is a technology that converts electrical signals carrying data into light, and transmits it over fibers. It can provide speeds that exceed by far the speeds achievable with the DSL or cable modem technologies. In France, from 2010 onwards, the main DSL operators – Orange, SFR and Free – have started to roll out fiber-to-the-home (FTTH) networks down to consumers’ premises.<sup>18</sup> Fiber networks are expected to replace the copper network at least in densely populated areas. Outside main municipalities, operators can also co-invest in their FTTH deployments to share the investment costs and expand FTTH coverage.<sup>19</sup> Table B.2 shows the number of municipalities in which Orange, SFR and Free deployed FTTH networks, and Table C.1 in the Appendix shows the number of municipalities in which co-investment between SFR and Orange took place as of 2014.<sup>20</sup>

To sum up, basic broadband (with speeds below 30 Mbps) is provided mainly with the DSL

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<sup>16</sup>In France, operators are deploying the second generation of VDSL, called VDSL2. With VDSL2, the maximum speed is achieved for lines of up to 300 meters. The connection speed decreases sharply for longer copper lines.

<sup>17</sup>In 2013, the authorization to implement VDSL was concerned only with the lines in direct distribution, i.e., those lines which were directly connected to a MDF. In October 2014, ARCEP generalized the use of VDSL to all eligible lines, i.e., all lines connected to a street cabinet.

<sup>18</sup>The FTTH technology is also called fiber-to-the-premises (FTTP).

<sup>19</sup>More precisely, the French regulator ARCEP has defined a list of so-called “very densely populated” areas. Outside these areas operators are obliged to propose a co-investment agreement to their competitors when they deploy a fiber network.

<sup>20</sup>We do not have information on other co-investment agreements between Orange and Free or between SFR and Free, but they are much less frequent.

technology by the incumbent Orange and LLU entrants (SFR, Free and a competitive fringe). Fast broadband (with speeds above 30 Mbps) is available on the FTTH networks of the main operators (Orange, SFR and Free), on the VDSL lines of the same operators, and in the areas where the cable operator, Numericable, has upgraded its network. Given the differences in network architectures, the cost of deploying VDSL is lower than the cost of upgrading cable, which itself is lower than the cost of rolling out a FTTH network.

## 4 Data

We use two data sets, which are available at the municipality level: (i) a data set on broadband infrastructure deployments by different operators; and (ii) a data set with socio-economic information. The first data set was collected from different proprietary and public sources, and contains information on the broadband technologies available on municipality-level. For each municipality in metropolitan France (excluding Corsica) and each year between 2010-2014, we observe the presence and identity of broadband operators deploying fiber and cable modem. We also observe the number and identity of LLU (and hence, DSL) operators and the number of active VDSL lines.<sup>21</sup> In the municipalities in which the local loop has been unbundled, there are between 1 and 6 LLU operators.

The data on fiber deployments by Orange was obtained directly from Orange. There are three possible states of fiber deployment by Orange at a given concentration point in a municipality: ‘deployed’, ‘in deployment’ or ‘planned’.<sup>22</sup> We consider that fiber by Orange is available in a municipality in a given year if there is at least one concentration point with status ‘deployed’.

The information on fiber deployment by the two main LLU competitors, SFR and Free, was obtained from their websites. SFR publishes regular press releases along with a map of France, in which all municipalities are listed where it has deployed fiber. For each year between 2010-2014 and each municipality, we observe whether SFR has deployed its network alone or in co-investment with another operator. The data on fiber deployments by Free was collected

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<sup>21</sup>This data set was obtained from Orange.

<sup>22</sup>The concentration point is a small street cabinet which aggregates cable lines and is connected to individual premises. There can be more than one concentration point in a given municipality.

from two unofficial websites run by Free users.<sup>23</sup> The data collected from these websites are consistent with the information available on other websites and with Free’s annual reports. For each municipality in metropolitan France and each year between 2010-2014, we know whether Free has active fiber connections.

The data on availability of cable modem was collected from the website of the cable operator, Numericable, for the years 2010-2014.<sup>24</sup> For each municipality and each year, we know whether Numericable has upgraded its cable network to provide fast broadband. As mentioned in the previous section, in October 2014 the French Competition Authority cleared the acquisition of SFR by Numericable. This transaction has no impact on our analysis since it took place after our data on deployment of fiber and cable was collected.

Finally, we obtained from Orange information on the roll-out of VDSL in municipalities. The deployment of this technology started at the end of 2013. For each municipality in years 2013-2014 we observe the number of lines upgraded to VDSL. We create a dummy variable which takes value one for the municipalities with a positive number of VDSL lines, and zero otherwise. Unfortunately, we do not know the identity of firms which operate VDSL lines in each municipality.

Our second data set contains socio-economic information at the municipality level, and was obtained from the French National Institute for Statistics and Economic Studies (INSEE). We have municipality-level data on the population size (defined as the number of households), population density (defined as the number of households divided by the surface of the municipality) and the number of flats and houses. This information is published with a two-year delay and available only until 2012. Since firms do not have access to more recent statistics, we consider that they make their entry decisions based on demographic information with a two-year lag. In addition, we have information on the average fiscal income per municipality in years 2010-2014, which was retrieved from the website of the General Direction of Public Finance (DGFIP). Table B.3 describes the variables used in the analysis.

The different data sets were merged using the unique INSEE code for each municipality. After merging the data sets we have information on 36,104 municipalities in France for the

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<sup>23</sup>See <http://francois04.free.fr/> and <http://serge.31.free.fr/>.

<sup>24</sup>We collected historical information using the wayback machine. See: [archive.org/web/](http://archive.org/web/).

years 2010-2014 resulting in 180,520 observations.<sup>25</sup> Table B.4 reports summary statistics for the variables used in the analysis. Tables C.2 and C.3 in the Appendix show summary statistics for year 2014 depending on the number of fiber operators and the number of LLU operators, respectively.

Figure B.1 shows the average number of households in thousand in municipalities where LLU, VDSL and fiber entries took place and cable was upgraded in a given year. This figure shows that over time, entry takes place in smaller municipalities for all technologies. Moreover, the size of municipalities in which fiber or cable entry takes place in a given year is much higher than the size of municipalities with LLU entry. Also, municipalities with fiber entry are bigger than municipalities with cable entry, while the size of municipalities with VDSL lies between the size of municipalities with LLU and cable.<sup>26</sup>

## 5 Econometric Models

In this section, we introduce the models of LLU and fiber entry that we estimate. There are substantial fixed costs of entry into local markets. As discussed in Section 3, an entrant who wants to provide DSL broadband services via LLU has to build its own backhaul network down to the incumbent's MDF, and then it has to locate its broadband equipments in the MDF, to which its broadband consumers are connected. Entry via fiber requires deploying fiber optic cables from the backbone network to every single house, which requires a much larger capital investment.<sup>27</sup>

In the previous literature on entry into broadband markets, both Xiao and Orazem (2011)

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<sup>25</sup>There were 36,192 municipalities in France in year 2014. Due to administrative changes in years 2010-2014 we lost information on 88 small municipalities. Some municipalities were also split into two and others merged, which led to changes in their names and INSEE codes.

<sup>26</sup>A similar pattern is observed for the density of population per squared kilometers in municipalities where LLU, VDSL and fiber entries took place and cable was upgraded.

<sup>27</sup>In general, the infrastructure fixed costs can be divided into country- and local market-level costs. Country-level costs are related to the deployment and maintenance of the backbone network, administration, marketing, etc. Local market-level costs are related to network deployment and administration within the municipality. These costs depend on factors such as the size of the geographic area to be covered, the number of premises and the spatial distribution of population. After the infrastructure has been deployed, marginal costs are relatively small and include factors such as modem rental expenditures and customer service. There are therefore economies of scale which imply that only a limited number of entrants can profitably operate in a municipality with certain socio-economic characteristics.

for the US and Nardotto et al. (2015) for the UK consider that investments made by LLU operators are sunk. The identification of sunk costs is based on a comparison of entry thresholds for markets which experienced entry with thresholds for markets without entry. The sunk costs imply that it takes less demand for an incumbent to continue operations than to support a new entrant. Table C.4 in the Appendix shows that there is a large number of LLU entries and exits in the time period considered. By contrast, Table C.5 in the Appendix shows a relatively small number of fiber entries and no exits at all. This difference lead us to take another approach to model LLU and fiber entry. We first present our model of LLU entry, and then our model of fiber entry.

## 5.1 LLU Entry

We want to determine the factors that explain how many operators enter a given local market via LLU to offer broadband services. We assume that at the end of each time period, firms decide whether to enter in the next period into new local markets and whether to continue operations in the ‘old’ local markets, where entry had already occurred in the previous periods. Firms form expectations about market demand, costs and competition with other firms. These expectations are fulfilled in equilibrium and the marginal firm enters or exits the market. We draw inferences on the profit determinants assuming a free entry equilibrium, where firms enter a local market if, and only if, it is profitable for them to do so. The model which we consider does not allow for simultaneous entry and exit.

The number of LLU entrants in municipality  $i$  at time  $t$  is then  $N_{it} = n \in \{0, 1, 2, 3, 4+\}$ , where 4+ refers to four entrants or more.<sup>28</sup> The discounted future profits of a firm having  $n$  competitors in market  $i$  at time  $t$  can be written as:

$$\pi_{it}^n = \alpha_t \ln S_{it} + X_{it} \beta_t - \mu^n I(N_{it} = n) + \epsilon_{it} \equiv \bar{\pi}_{it}^n + \epsilon_{it}, \quad (1)$$

where  $S_{it}$  is the market size approximated by the number of households,  $X_{it}$  is a vector of other characteristics of municipalities, which are potential determinants of profits (including

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<sup>28</sup>Since there is only a small number of markets with more than four entrants, we truncate the number of entrants to four.



income, population density, and the share of flats in the total number of premises). We interact selected characteristics with time, as denoted by  $\beta_t$ . We also consider that firms' profits may differ in broader geographic regions due to other factors, which we approximate by a set of regional dummy variables. In addition we use a dummy variable which takes value of one for municipalities in which ADSL broadband was launched before year 2000. These municipalities should be more attractive for entrants.<sup>29</sup> Finally,  $\mu^n$  represents the negative effect on profits from the  $n^{th}$  firm and  $\epsilon_{it}$  is the error term. This reduced form profit specification is similar to the specifications proposed by Xiao and Orazem (2011) and Nardotto et al. (2015), and does not distinguish between variable profits and fixed costs of production, as in Bresnahan and Reiss (1991).

In France, LLU has been regulated since 2000 and in larger municipalities (in terms of population size) the first LLU entry took place before year 2010. From 2010 onwards, when firms started to deploy fiber, most of LLU entries took place in municipalities which are too small for fiber and cable to be profitably deployed. We therefore consider that the local presence and the number of LLU operators are not influenced by competition with fiber and upgraded cable, at least for the vast majority of municipalities. Still, we cannot exclude that the number of LLU entrants in the largest municipalities would be greater in the absence of fiber or cable networks.<sup>30</sup>

The specified profits  $\pi_{it}^n$  include the non-sunk part of fixed costs. Since profits are not observed,  $\pi_{it}^n$  is a latent variable. Firms may also have to incur a sunk cost  $SC$  to enter a local market, which cannot be recovered when they exit. We assume that all entrants have the same entry costs regardless of the order of entry. The model of entry which we consider does not account for heterogeneity between firms, which is problematic because firms may have different cost structures. There are firms of different size and geographic presence. Also, the main LLU operators, SFR and Free, deploy fiber networks and provide mobile services, which cannot be

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<sup>29</sup>We use year 2000 because in alternative regressions with a set of dummy variables for different years of launching ADSL, only dummy variables for years 2000 and before are significant. There are 2,552 municipalities in which ADSL was launched before year 2000, which are the most attractive ones for the provision of broadband services.

<sup>30</sup>We observe in the data that in all municipalities, the entry of the first LLU operator took place before entry of the first fiber operator. Moreover, for 1,013 out of 1,071 municipalities with upgraded cable in 2014, the entry of the first LLU operator took place before cable was upgraded. For the remaining 58 municipalities, the first LLU entry took place in the same year or after cable was upgraded.

offered by smaller LLU entrants. A similar problem regarding heterogeneity of firms was noted by Xiao and Orazem (2011), who do not know the identities of firms and whether entrants use the DSL or cable technologies.

There are three different cases in which we may observe that at time  $t$  in market  $i$  there are  $N_{it} = n$  active firms. In the first case, there were fewer than  $n$  firms in period  $t - 1$  and one or more firms have entered in period  $t$ , so that  $N_{it} > N_{it-1}$ . In this case, for the  $n^{th}$  marginal firm, the expected discounted benefits from entering must exceed the sunk cost of entry. But for the  $(n + 1)^{th}$  marginal firm, the benefits from entering must be lower than the sunk cost, which can be expressed as follows:

$$\textbf{Case 1, net entry: } N_{it} > N_{it-1} \text{ if } \pi_{it}^n \geq SC \text{ and } \pi_{it}^{n+1} < SC. \quad (2)$$

In the second case, no firm has entered or exited the market in period  $t$ , which means that there were  $n$  firms in period  $t - 1$  and  $N_{it} = N_{it-1}$ . In this case, the  $n^{th}$  marginal firm stays in the market because its expected discounted benefits from continuation exceed 0. But for the  $(n + 1)^{th}$  marginal firm, the benefit from entering is below the sunk cost of entry, which can be specified as:

$$\textbf{Case 2, inaction: } N_{it} = N_{it-1} \text{ if } \pi_{it}^n \geq 0 \text{ and } \pi_{it}^{n+1} < SC. \quad (3)$$

Finally, in the third case, there were more than  $n$  firms in period  $t - 1$  and one or more firms have exited the market in period  $t$ , which implies that  $N_{it} < N_{it-1}$ . In this case, the market becomes unprofitable when more than  $n$  firms stay in operation. The  $(n + 1)^{th}$  marginal firm expects that it would be unprofitable to remain in the market, and decides to exit the market. Once this firm has exited the market, the  $n^{th}$  marginal firm expects positive profits, which can be expressed as:

$$\textbf{Case 3, net exit: } N_{it} < N_{it-1} \text{ if } \pi_{it}^n \geq 0 \text{ and } \pi_{it}^{n+1} < 0. \quad (4)$$

Using the profit specification (1), the above inequalities can be combined to derive the

following probability of observing  $N_{it} = n$  entrants in market  $i$  at time  $t$ :

$$Pr(N_{it} = n) = \Phi(\bar{\pi}_{it}^n - SC \cdot I_{it}^+) - \Phi(\bar{\pi}_{it}^{n+1} - SC \cdot (I_{it}^+ + I_{it}^0)), \quad (5)$$

where  $\Phi(\cdot)$  denotes the cumulative normal distribution function, and  $I_{it}^+ \equiv I(N_{it} > N_{it-1})$  and  $I_{it}^0 \equiv I(N_{it} = N_{it-1})$  are indicator variables which show whether the number of firms increased (subscript  $+$ ) or remained constant (subscript  $0$ ). The parameter vector  $\theta = [\alpha, \beta, \mu, SC]$  is estimated by maximizing the following log-likelihood function:

$$\hat{\theta} = \arg \max \sum_{i=1}^M \sum_{t=1}^T y_{it} \ln(Pr(N_{it} = n|\theta)), \quad (6)$$

where  $y_{it}$  takes value of 1 if  $N_{it} = n \in \{0, 1, 2, 3, 4+\}$ , and 0 otherwise. As discussed in Nardotto et al. (2015), following Aguirregabiria (2012) this model can be interpreted as a “semi-structural” dynamic model of free entry and exit.

## 5.2 Fiber Entry

We use a similar approach to model fiber entry. But since fiber entry takes place in a much smaller number of local markets and we do not observe any exit, we are not able to identify sunk costs in this case. Without sunk costs (i.e., with  $SC = 0$ ), the model of fiber entry is static and reduces to a standard ordered logit or probit model, similar to Bresnahan and Reiss (1991). Since we believe that there are significant sunk costs in the fiber industry, the estimates of entry thresholds resulting from this model may be biased. Another issue with our modeling approach is that we do not account for heterogeneity of firms, which is also a limitation of the model of LLU entry discussed before.

The discounted value of future profits of a fiber entrant can be also specified by equation (1), but with  $n \in \{0, 1, 2, 3\}$ . We then use the same set of socio-economic characteristics as determinants of profits for fiber entrants. Apart from the absence of sunk costs, there are two other differences between the model of LLU entry and the model of fiber entry. First, the operators which decide to deploy fiber in a local market (Orange, SFR and Free) already offer DSL ser-

vices, and therefore face an opportunity cost when investing in a new infrastructure.<sup>31</sup> Second, the future profits of a potential fiber entrant, net of its opportunity cost, are affected by the competition from other broadband technologies, which are already available in the local market. We account for these two issues as follows.

First, since we know the identity of all LLU operators which are present in every municipality, we create a variable which represents the number of LLU entrants in the local market, excluding the fiber operators SFR and Free. In the data, we observe that SFR and Free deploy fiber only in markets where they also have LLU operations. In general, firms which have invested into LLU in an area have lower incremental costs of investing into fiber. Therefore, the data would tell us that there is a positive effect of entry via LLU on fiber deployment by the same firm. To circumvent this problem, we analyze whether the number of other LLU operators has a positive or a negative impact on fiber entry. As mentioned in Section 5.1, in municipalities in which fiber was deployed in years 2010-2014, the entries of LLU operators took place at an earlier stage. We therefore consider that the number of LLU operators is exogenous in the model of fiber entry.

In Appendix A, we develop a simple model to analyze the impact of the number of LLU competitors on the incentive to invest in fiber. We show that this impact is *a priori* ambiguous: a higher number of LLU competitors means that the profitability of fiber investment is lower, but at the same time it implies lower profits from DSL operations, and hence a lower opportunity cost of investing in fiber. We then show that a higher number of LLU competitors can increase the incentives to enter with fiber if the quality improvement brought by fiber is sufficiently high.

Second, the incentives to deploy fiber may be influenced by the availability of the VDSL technology in the local market. In the base model specification, we also treat the VDSL variable as exogenous, i.e., as independent of the deployment of fiber, even though firms may decide to upgrade copper lines to VDSL instead of investing in fiber. To circumvent this problem, we also estimate the same model for years 2010-2012, in which VDSL was not yet deployed in the market. Based on our theoretical model of Appendix A, we expect that the presence of VDSL has a negative effect on fiber entry.

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<sup>31</sup>Orange uses its own copper network to offer broadband services. SFR and Free use LLU or bitstream access to deliver broadband. Bitstream access is a wholesale broadband offer, whereby a broadband operator (typically, the incumbent operator) leases access to its broadband network to third parties to enable them to offer broadband services.

Finally, the decision of Numericable to upgrade its cable network to fast broadband and the availability of upgraded cable in the municipality can influence the decision to enter with fiber. As discussed in Section 3, the cable infrastructure was deployed before fiber, but the upgrade to fast broadband took place in parallel to fiber deployments and may be endogenously determined. In the base specification of our model, coverage with upgraded cable is considered to be independent from the entry decisions by fiber operators. In another model specification, we also allow this variable to be endogenous; the cable operator is then considered to be one of the fiber entrants. The presence of upgraded cable can have *a priori* either a negative or a positive effect on fiber entry because the competition from cable affects both pre- and post-investment profits. In Appendix A, we show that the presence of cable can increase the incentives to invest in fiber if strong investment spillovers are present, that is, if the fiber entrant incurs a lower entry cost due the presence of the cable operator.

Since, as shown in Table C.6 in the Appendix, Orange is the market leader with a presence in almost all municipalities in which fiber is deployed, we also estimate a model in which the zero/one entry decision by Orange is regressed on the same set of explanatory variables. Similar to our base model, we study how the deployment of fiber by Orange in a local area is affected by: (i) the number of LLU entrants (excluding SFR and Free); (ii) the availability of VDSL; and (iii) the availability of upgraded cable.

## 6 Estimation Results

### 6.1 LLU Entry

Table B.5 shows the estimation results for the model of LLU entry. Model I is estimated without sunk costs (ordered logit model) and Model II allows for non-zero sunk costs. Based on the value of the log-likelihood function, the preferred model is Model II. Sunk costs seem to play an important role when it comes to entry into broadband markets via LLU and they can thus represent a barrier to entry. Market size and density of population affect positively and significantly LLU entry. We use in the estimation the interaction of population density and time dummies to determine whether it becomes easier over time to enter less densely populated

areas, which may be due to technological progress and/or declining costs of equipment. The interaction terms of the density of population with time dummies are significant, but do not suggest a particular increasing or decreasing trend. At the same time, the coefficients of time dummies increase over time. The share of flats in the total number of residencies is significant and negative, which implies that there is less LLU entry in markets with a larger share of flats. This result is not intuitive and if there are economies of density the opposite could be expected. Furthermore, a higher level of income has a positive impact on LLU entry. Finally, municipalities in which ADSL broadband was launched before year 2000 are more profitable.

Our estimation results confirm the role of market size and other market characteristics in determining the number of entrants. We use the model estimates to compute entry thresholds for LLU entrants. For each market  $i$  in period  $t$  we calculate entry thresholds for  $n = 1, 2, 3, 4+$  LLU operators by solving the critical market size which sets the profits to zero:  $S_{it}^n = \exp((-X_{it}\beta_t + \mu^n I(N_{it} = n) + SC)/\alpha_t)$ . The average entry thresholds for LLU are shown in Table B.6. To compute these entry thresholds we use the characteristics of a representative municipality (i.e., the average characteristics from all municipalities weighted by the number of households). The computed thresholds represent the minimum size of local market which is required to accommodate a given number of LLU operators.

The entry thresholds for the first LLU operator are about 5 times higher in the model with sunk costs than without. Thus, when sunk costs are ignored entry thresholds tend to be underestimated. We now discuss the entry thresholds for the model with sunk costs. The average entry thresholds for LLU decrease substantially over time. According to our estimates, in 2014, 473 households in a municipality were enough for the first LLU entrant to break even and 1,356 households were needed for the second LLU operator to enter. According to our data, the average size of municipalities in which the first LLU entry took place in 2014 was 290 households, which is about 40% below our estimate.<sup>32</sup>

The number of households needed for the third entrant was much higher at 34,190, and for the

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<sup>32</sup>The difference between the estimated threshold required for the first (and additional) operator to enter municipality and the average municipality population by year of entry is due computation. The average thresholds are computed for the whole population, i.e., for 36,104 municipalities with the number of households used as weights. On the other hand, the average municipality population by year of entry is computed for a smaller number of municipalities in which entry took place.

fourth entrant 155,236 households were required. This reflects the fact that there is only a small number of municipalities with 3 and especially with 4 entrants. As shown in Table C.3 in the Appendix, the municipalities with 3 and 4 LLU entrants are much larger in population size than municipalities with 1 and 2 entrants. These are also typically municipalities in which upgraded cable and fiber networks are deployed. When 3 LLU operators are present in a municipality, in 97% of cases SFR and Free are among them. The third operator is typically Bouygues Telecom or Axione, where Axione provides broadband services for the business market. This suggests that late entry of LLU operators which are active only on a smaller geographic scale is difficult.

The number of households needed for the first LLU entrant to break even in 2011 was 1,186. Between 2011 and 2014 the entry threshold declined by about 60%. This reduction in entry thresholds may result from a decline in the cost of technology and equipments. It may be also due to regulations which have reduced the wholesale costs of LLU for alternative operators. For example, in January 2012, the LLU price was slightly reduced by ARCEP from €9 to €8.80. A change in the regulation of bitstream access in France in 2011 may also have led operators to favor LLU over bitstream access.<sup>33</sup>

In the model of LLU entry, we account for heterogeneity between municipalities by means of observable market characteristics and regional dummy variables. We also cluster the error terms using the variable that identifies the panels. But we do not account for unobservable characteristics at the municipality level, which would require estimating a model with sunk costs and serially correlated error terms, as shown in Nardotto et al. (2015). We may thus overestimate the impact of sunk costs by ignoring serial correlation in the error terms. We also do not allow for heterogeneity between firms, even though LLU entrants such as SFR and Free may have different cost structure than smaller LLU operators which do not invest in fiber networks.

## 6.2 Fiber Entry

Table B.7 shows the estimation results for the models of fiber entry. As discussed in the previous section, we were not able to estimate a model with sunk costs due to convergence issues, which

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<sup>33</sup>In 2011, the French regulator ARCEP removed the obligation of cost orientation for bitstream access in areas with wholesale competition.

may be caused by the particularities of our data on entry of fiber. Model specification (1) is an ordered logit model without random effects. In this model, and all other models which we estimate without random effects, we cluster the error terms using the variable that identifies the panels. Model specification (3) is a random effects ordered logit for panel data, which takes into account heterogeneity between local markets. Compared with specification without random effects, all significant coefficients have the same signs but increase in magnitude. There is significant heterogeneity across local markets as reflected by a significant estimate of variance component. Model specification (2) instead of random effects includes a dummy variable for co-investments between Orange and SFR. This variable is endogenous since firms decide on co-investment and entry simultaneously. The coefficients for this variable are highly significant and positive, which indicates that deployment of fiber is easier in co-investment due to shared costs.<sup>34</sup> But the inclusion of co-investment dummy does not impact significance of other variables, except VDSL.

We estimate the same three model specifications for a sub-sample of municipalities with population of 250 households or more, but without Paris and cities which represent a single municipality with population above 100,000 (Model II in Table B.7).<sup>35</sup> We reduce the sample to larger municipalities because we observe only 24 fiber entries in municipalities with population below 250 households. We drop Paris and large cities because from the start of our data there were already 3 fiber entrants in these most attractive municipalities. The estimates for the reduced sample change only marginally.

The estimation results for all three models lead to similar conclusions. The availability of competing technologies in a local market has a significant impact on fiber entry. First, a greater number of LLU entrants has a significant and positive impact on fiber entry.<sup>36</sup> In municipalities with many LLU entrants, Orange, Free and SFR have more incentives to deploy fiber networks. Thus, a larger number of LLU competitors affects less the profits derived from a fiber network

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<sup>34</sup>This is consistent, for example, with the theoretical framework proposed by Bourreau, Cambini and Hoernig (2017), which suggests that co-investment leads to larger coverage than standard access.

<sup>35</sup>In our sample of 36,104 municipalities, there are 14,006 municipalities with population of 250 households and more. We then drop from this sample 20 municipalities in Paris and 8 municipalities with a population of 100,000 households or more: Bordeaux, Lille, Montpellier, Nantes, Nice, Rennes, Strasbourg and Toulouse.

<sup>36</sup>The number of LLU competitors excludes SFR and Free to assess the impact of other LLU competitors on fiber deployment. The impact of the number of LLU operators on fiber entry is similar when SFR and Free are counted as LLU competitors.



than the opportunity cost due to lost DSL profits. In light of our model of Appendix A, this can be explained by the vertical differentiation between fiber services and DSL services, which mitigates the impact of LLU competitors on fiber profits.<sup>37</sup>

We find that fiber entry is more likely in areas where the cable operator Numericable upgraded its network to provide fast broadband services. Within our theoretical framework in Appendix A, this suggests the presence of investment spillovers, which reduce the cost of fiber entry when upgraded cable is present. Also, based on discussions with industry experts, customer acquisition strategies of fiber operators are more aggressive in municipalities which are covered by cable. Firms deploy fiber to secure the migration of their DSL customers to fiber, who may be otherwise lost to the cable rival. The presence of cable operator would thus reduce substantially the opportunity cost of investing in fiber, thereby enhancing investment incentives.

Next, we find that upgrading DSL lines to the VDSL technology, a process which started in 2013, has a negative impact on fiber deployment. Only in model with co-investment dummy VDSL becomes insignificant. This result is consistent with our model in Appendix A, which suggests that when DSL competitors upgrade to VDSL, the incentives to deploy fiber are lower. The negative effect of the VDSL variable can also be due to the fact that fiber and VDSL connections are supply substitutes. When broadband operators have the option of investing in the VDSL technology, they have less incentives to deploy fiber networks. Furthermore, since VDSL deployment is much faster than fiber deployment, when one firm deploys VDSL, its competitors may have an incentive to react quickly and deploy the same technology. Unfortunately, we do not know the identity of the firms which deploy VDSL in particular municipalities, and therefore we are unable to identify these different effects.

Since fiber operators make decisions to enter new local markets simultaneously with Numericable's decision to upgrade its cable network, the variable for presence of cable should be considered as endogenous. In an alternative model specification, Model I in Table C.7 in the Appendix, we consider that the cable network operator is one of the fiber entrants. In this

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<sup>37</sup>In an alternative model specification, we replaced the LLU variable by its lagged values, thus losing the first year of data. The estimation results are very similar, with a positive coefficient for the number of LLU operators. We also have information on the number of unbundled lines in municipalities but for the year 2014 only. All three regressions are estimated for the year 2014, using the share of unbundled lines instead of the number of LLU entrants. The estimated coefficient for the number of unbundled lines is also positive and significant.

way, we allow cable coverage to be determined endogenously together with the number of fiber entrants.<sup>38</sup> This model specification is also estimated with random effects for municipalities and with a dummy variable for co-investments between Orange and SFR. The impact of LLU on fiber/cable entry remains unchanged. The limitation of this approach is that cable and fiber operators are considered to have the same cost structure and sell the same products.

As shown in Figure B.2, and observed in our data, there are many municipalities in which fiber is deployed but not cable, or the other way around. There is essentially only one region in which both technologies (fiber and upgraded cable) have a strong presence, which is Ile-de-France (i.e., the area around the city of Paris). Cable has a strong regional presence in Alsace and Lorraine, where almost no fiber is deployed except for major cities. This suggests that there is some geographic separation with respect to the deployment of fiber and upgraded cable. Except for the largest cities, these two technologies seem to avoid entering territories of each other. Moreover, as discussed above, the deployment of cable takes place in smaller and less densely populated municipalities in comparison to fiber. However, contrary to what is suggested by these observations, we find a positive impact of cable on entry of fiber networks, even when largest cities are excluded from the sample.

Furthermore, fiber operators can decide to deploy VDSL technologies instead of investing in fiber, and hence the VDSL variable may also be endogenous. Model II in Table C.7 in the Appendix shows the estimation results for years 2010-2012, in which VDSL was not yet deployed in the market. This model is also estimated with random effects and with a dummy variable for co-investments. The impact of LLU and cable on fiber entry remains unchanged for years 2010-2012.

Finally, Model III in Table C.7 in the Appendix is a logit model of fiber entry by Orange. We also take into account the correlation of the error terms by estimating a random effects model for panel data. But since Orange is always one of the co-investing operators we cannot estimate this model with a dummy variable for co-investments between Orange and SFR. For both estimated model specifications, the results confirm a significant and positive impact of the

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<sup>38</sup>We also estimated an alternative specification of this model, in which we took into account the merger between Numericable and SFR in 2014. More precisely, we considered that in year 2014 one of these two firms exited the local markets in which both of them had operations. This alternative model yielded similar estimation results.

number of LLU competitors on fiber entry by Orange.

In all model specifications, the socio-economic characteristics of local markets affect fiber entry. The main variable which influences entry is the market size, measured by the number of households in the local market. The population density has also a significant positive impact on fiber entry. This means that fiber entry is more profitable in densely populated areas. The negative and increasing coefficients of the interaction terms of population density and year dummies indicate that it becomes easier over time to enter areas with lower density of population. The share of flats in the total number of residencies has a positive impact on fiber entry, which may reflect lower costs of deploying fiber in areas with many apartment blocks. Furthermore, we find that a higher level of income has a positive impact on fiber entry. Finally, municipalities in which ADSL broadband was launched before year 2000 are more profitable.

### 6.3 Future Deployment of Fiber

We use the model estimates and formula shown before to compute entry thresholds for fiber operators, which are reported in Table B.8. These numbers are computed using the characteristics of a representative municipality (i.e., the average characteristics from all municipalities, weighted by the number of households). The computed thresholds represent the minimum size of local market required to accommodate a given number of fiber operators.

We discuss the entry thresholds for fiber based on model specification (3) in Table B.7, which is estimated with random effects for a sub-sample of municipalities. We do not consider that entry with fiber is realistic in municipalities with population below 250 households. The average entry thresholds for fiber are much higher than for LLU, which reflects a higher scale of investment required to enter a market with fiber, as discussed in Section 3. According to our estimates, in 2014, the first fiber operator needed 17,961 households to break even, the second operator needed 27,328 households, and the third one needed 137,984 households. Our entry thresholds may be underestimated, since we cannot account for the presence of sunk costs. However, according to our data, the average size of municipalities in which first fiber entry took place in 2014 was 7,879 households, which is significantly below our estimates.<sup>39</sup>

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<sup>39</sup>As already mentioned, the difference between the threshold required for the first (and additional) operator to enter municipality and the average municipality population by year of entry is due to computation. Moreover,

Since the ratio of entry thresholds for the second operator relative to the first one is 1.5, our estimates indicate that it is easier to be the follower. This may be because for the second entrant it is easier to get access to infrastructure which had been laid out by the first entrant. On the other hand, the ratio of entry threshold for the third operator relative to the second one is 5.0. This implies that entry of a third operator is much harder, which is reflected by a smaller number of municipalities with three fiber networks, as shown in Table C.5. This suggests that the industry is likely to remain a duopoly of SFR and Orange, with Free being a smaller market player deploying fiber in the largest municipalities only. The market position of SFR as the second fiber network was further strengthened in 2014 by the merger with Numericable.

Our estimates suggest that competition with LLU entrants contributed to the expansion of fiber networks. To quantify this effect, we compute the fiber entry thresholds in the absence of LLU operators other than Free and SFR; the results are shown in Table B.8. We find that the average entry threshold for the first fiber operator in 2014 would be higher by about 13% in the absence of competition from LLU operators. Fiber entry is also positively influenced by competition with cable and negatively influenced by competition with VDSL. Overall, without LLU, cable and VDSL, the entry threshold of the first fiber operator would be higher by 4% in 2014.

As in the case of LLU, entry thresholds decline substantially over time. Between 2010 and 2014, total decline amounts to about 69% (or about 26% per year during four years). Again, this reduction in entry thresholds may result from a decline in the cost of technology and equipments. If the cost reductions continue at the same pace of 26% per year, the entry threshold for the first fiber operator may drop from 17,961 households in 2014 to 3,065 households in 2020, and further to 702 households in 2025.

We can compute the share of population of France living in municipalities with 3,065 households and more, which according to our calculation amounts to 55% (14,957 out of 26.996 million households in France), who live in 1,343 out of 36,104 municipalities. The share of population living in municipalities with 702 households and more amounts to 78% (21,172 million households), who live in 5,902 municipalities. We can thus conclude that while a significant share of

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in the estimated model we do not account for LLU entries by SFR and Free, which facilitate fiber entry by the same operators in smaller municipalities.

population might be covered by 2020, there is little perspective to achieve the ambitious 2025's goal to cover the whole population of the country with fiber. To achieve this goal, considerable public investments will be required.

## 7 Conclusion

In this paper, we analyzed the impact of local market competition on fiber investments using panel data on 36,104 municipalities in metropolitan France in years 2010-2014. We estimated two models of entry into local markets: (i) a model of entry via local loop unbundling (LLU), to offer DSL services; and (ii) a model of entry via the deployment of a fiber network to deliver fast broadband. We also estimated the determinants of the incumbent's decision to deploy fiber in municipalities.

We find that a higher number of LLU competitors, hence a less concentrated DSL market, makes fiber entry more likely. We explain this result by the vertical differentiation between fast broadband and basic broadband, which implies that a higher number of LLU competitors reduces less the profits obtained from fiber operations than the opportunity cost of investment due to lost DSL profits. Furthermore, we observe in the data that fiber deployment by SFR and Free is always preceded by entry via LLU. In general, firms which have invested into LLU in an area have a lower incremental cost of investing into fiber.

The presence of upgraded cable in a municipality has a positive impact on fiber deployment. Fiber entrants may benefit from investment spillovers, which reduce the cost of rolling-out fiber when upgraded cable is present. Firms offering DSL services may also fear being preempted by the cable operator for the delivery of fast broadband services, which encourages them to deploy fiber. In addition, we find that the deployment of VDSL, which provides higher Internet speeds on the copper network, slows down fiber deployment. An upgrade of LLU competitors to VDSL thus reduces the profit incentive from fiber deployment. Firms may also choose to upgrade copper lines on the legacy network to VDSL, instead of investing in fiber.

Our results have important policy implications, as they show that competition from the LLU operators or cable operator encourages, rather than discourages, fiber investments.

We show that the main variables which influence fiber deployment are the market size and

density of population. The market size required for the first and each additional operator to enter decreases over time, which means that entering less densely populated municipalities becomes easier over time. Entry thresholds for LLU operators are substantially smaller than for fiber operators, which reflects a much smaller scale of investment needed to launch LLU.

Our results suggest that despite a decrease in fiber entry thresholds, the vast majority of municipalities in France will remain unprofitable for fiber deployment by private firms. According to our model, the number of households needed for a profitable entry of the first fiber operator declined by 69% between 2010-2014. If the speed of decline continues at the same pace of about 26% per year, 55% of population in France will be covered by fiber by 2020 and 78% by 2025. This number falls short of full coverage, which is the new target announced by the European Commission for 2025. There is therefore a need for public involvement to achieve the superfast broadband deployment objectives.

Our analysis has important limitations, which are due to the particularities of the broadband market and data constraints. First, since LLU access regulation is in place in the whole country, we cannot identify the impact of a change in regulation on fiber deployments. Therefore, in this paper we evaluate the impact of competition from LLU entrants and other broadband providers on fiber deployments, rather than the impact of LLU regulation *per se*. Second, the models of entry which we estimate do not account for heterogeneity between firms, which is clearly present due to differences in cost structures between operators and technologies. We were also not able to estimate sunk costs for fiber entry. We may attempt more advanced modeling of a discrete entry game when the broadband industry in France develops further and the coverage by fiber networks expands.

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## Appendix A: Model of Fiber Entry

In this appendix, we develop a simple model of investment to rationalize why the incentives to deploy fiber in a municipality can (i) increase with the number of LLU competitors, (ii) decrease with an upgrade of DSL competitors to VDSL, and (iii) increase when upgraded cable is available in the municipality.

**Model.** An operator, firm 0, contemplates deploying a new-technology (fiber) network in a municipality, which offers a higher quality of service compared to the old technology (copper), for an investment cost of  $c$ . Prior to investment, firm 0 operates an old-technology network, and faces competition from  $n \geq 1$  rival firms, indexed with  $i = 1, \dots, n$ , which also use the same old technology.

Firm 0's incentive to invest in the new technology is defined as the difference in profit that the firm can earn if it invests in a fiber network compared to the profit it would earn if it did not invest, which we refer to as the firm's *profit incentive*. Formally, firm 0's profit incentive is given by  $PI \equiv \pi_{\text{post}}^N - \pi_{\text{pre}}^O$ , where  $\pi_{\text{pre}}^O$  denotes firm 0's pre-investment profit (with the old technology  $O$ ), and  $\pi_{\text{post}}^N$  its post-investment profit (with the new technology  $N$ ). Therefore, firm 0 deploys a fiber network in the municipality if and only if  $PI \geq c$ .

We use the model of quantity competition with quality differentiation of Katz and Shapiro (1985), which has been used in the literature to model competition in the broadband market (see, e.g., Foros (2004) and Bourreau et al. (2012)). The indirect utility of a consumer of type  $\tau$  is  $U = \tau + s_i - p_i$ , where  $s_i$  and  $p_i$  denote the quality and price of firm  $i = 0, \dots, n$ . Consumers' types are uniformly distributed over  $(-\infty, 1]$ . Firms compete in quantities and the marginal cost is normalized to zero. We denote the quality of the old-technology by  $s_O$ , and the quality of the new technology by  $s_N$ , with  $s_N > s_O$ . Hence, we have  $s_i = s_O$  for all  $i = 1, \dots, n$ , whereas firm 0 has quality  $s_0 = s_O$  before investing and  $s_0 = s_N$  after investing. We assume furthermore that  $s_N < 1 + 2s_O$ , which ensures that the firms that use the old technology remain active when the new technology is deployed. That is, the new technology is not a "drastic" innovation that replaces the old technology, which is consistent with our market observations.

Assuming that all firms are active in equilibrium, their quality-adjusted prices should be the

same, that is, we have  $p_i - s_i = p_j - s_j = \hat{p}$ , for all  $i$  and  $j$ . The type of the marginal consumer is thus  $\tau = \hat{p}$ , and the total demand is  $Q = \sum_{i=0}^n q_i = 1 - \hat{p}$ , which yields the inverse demand for firm  $i$ ,  $p_i = 1 + s_i - Q$ . Each firm  $i$  maximizes its profit  $\pi_i = p_i q_i$  with respect to its quantity  $q_i$ . The pre-investment equilibrium profits are then:

$$\pi_{\text{pre}}^O(n) = \left( \frac{1 + s_O}{n + 2} \right)^2.$$

The post-investment equilibrium profits are:

$$\pi_{\text{post}}^O(n) = \left( \frac{1 + 2s_O - s_N}{n + 2} \right)^2.$$

for firms  $i = 1, \dots, n$  and

$$\pi_{\text{post}}^N(n) = \left( \frac{1 + s_N + n(s_N - s_O)}{n + 2} \right)^2.$$

for firm 0.

**Impact of local market structure.** We start by looking at the impact of the number of LLU competitors in the municipality,  $n$ , on fiber entry.

We find that  $\partial \pi_{\text{pre}}^O / \partial n \leq 0$  and  $\partial \pi_{\text{post}}^N / \partial n \leq 0$ : intuitively, more intense competition reduces both the profitability of the investment ( $\pi_{\text{post}}^N$ ) and the opportunity cost of investment in terms of foregone profits ( $\pi_{\text{pre}}^O$ ). Therefore, the impact of local market structure on firm 0's investment incentive is *a priori* ambiguous. In our specific setting, we find that which effect dominates depends on the quality improvement brought by the new technology:

**Proposition 1.** *The profit incentive increases with the number of competitors in the market if the quality of the new technology is high enough, relative to the old technology; otherwise, it decreases with the number of competitors.*

*Proof.* We have  $\partial \text{PI} / \partial n \geq 0$  if and only if

$$s_N \geq 1 + 2s_O - \frac{1 + s_O}{n + 1}. \quad (7)$$

Note that condition (7) is compatible with our assumption that  $s_N < 1 + 2s_O$ . Therefore, for a given number of competitors  $n$ , if  $s_N$  is sufficiently high so that (7) holds, a small increase in

the number of competitors leads to higher investment incentives.  $\square$

In our framework, this result suggests that if fiber corresponds to a sufficiently high quality improvement for consumers over DSL, then we should expect *higher* investment incentives when the number of LLU competitors is higher.

Note that this proposition extends the results of Yi (1999) and Belleflamme and Vergari (2011) to a setting with quality differentiation. Yi (1999) shows that under quantity competition with homogeneous goods, the incentives to invest in a small cost-reducing innovation decrease with the number of competitors. Belleflamme and Vergari (2011) analyze a model of price or quantity competition with a linear demand and horizontally differentiated products. They show that the relation between the profit incentive and the number of firms can be non-monotonic. We find a result similar to the one obtained by Belleflamme and Vergari, but in a setting with vertical differentiation.

Simple comparative statics also show the following:

**Proposition 2.** *For a given local market structure, if the firms that use the old technology upgrade their technology to a slightly higher quality, then firm 0 has less incentives to invest in the new technology.*

*Proof.* For a given number of competitors  $n$ , we have indeed  $\partial PI / \partial s_O < 0$ .  $\square$

In our context, this result suggests that if DSL firms upgrade their network to VDSL, the incentives to invest in fiber are reduced.<sup>40</sup>

**Impact of cable entry on fiber entry.** Finally, we discuss the impact of the presence of upgraded cable in the municipality on firm 0's incentives to invest in fiber, compared to a situation without cable. As above, firm 0 contemplates investing in the new technology to replace its old technology. We consider now that firm 1 is a cable operator, providing the same quality of service than fiber. The remaining firms  $i = 2, \dots, n$  still use the old technology of lower quality. Define  $PI^C$  as firm 0's profit incentive in this case. Then, the presence of cable reduces

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<sup>40</sup>This result is also true if only one old-technology firm upgrades its network.

firm 0's investment incentives if

$$PI^C \leq PI, \quad (8)$$

and increases its investment incentives otherwise, where  $PI$  represents firm 0's profit incentive when firm 1 uses the old technology.

In the specific Katz and Shapiro setting that we have adopted, condition (9) is always satisfied, meaning that cable entry and fiber entry are strategic substitutes.

However, as argued by Bourreau et al. (2012), this is not necessarily true in general. In particular, they show that if investment decisions are taken sequentially and the follower benefits from "investment spillovers" from the leader's entry, the leader and follower's investment decisions can become strategic complements.

Formally, Bourreau et al. (2012) consider that the investment cost is  $c$  for the leader, and  $c/(1+\gamma) \leq c$  for the follower, where  $\gamma \geq 0$  represents the degree of investment spillovers. It might be less costly to enter the market for the follower than for the leader because of specific costs incurred by the latter and not the former, in terms of infrastructure deployment or marketing. For example, the leader may have to advertise to make uninformed consumers aware of its new service (or to make them perceive the increase in quality). Such advertising has a public good nature, and the follower benefits from it, which reduces its advertising costs, and hence its entry costs. Building on this idea, we can show the following result:

**Proposition 3.** *Assume that there are investment spillovers  $\gamma \geq 0$ . Then, the presence of upgraded cable in the municipality increases the incentives to invest in fiber if the degree of spillovers  $\gamma$  is sufficiently high.*

*Proof.* The presence of cable increases investment incentives if and only if

$$PI^C - \frac{c}{1+\gamma} \geq PI - c,$$

which is equivalent to

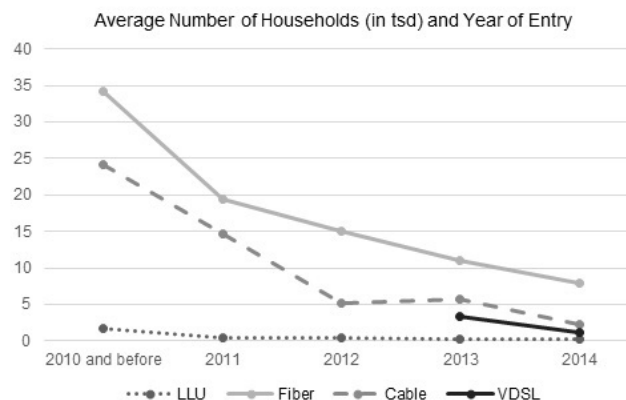
$$\gamma \geq \frac{c}{PI^C - PI + c} - 1. \quad (9)$$

Since  $PI^C \leq PI$  in our Katz and Shapiro setting, then the right-hand side of (9) is positive.  $\square$

This result therefore suggests that the impact of cable on fiber entry depends on whether such a second-mover advantage exists.

## Appendix B: Figures and Tables

Figure B.1: Municipality statistics by year of entry of broadband technologies.



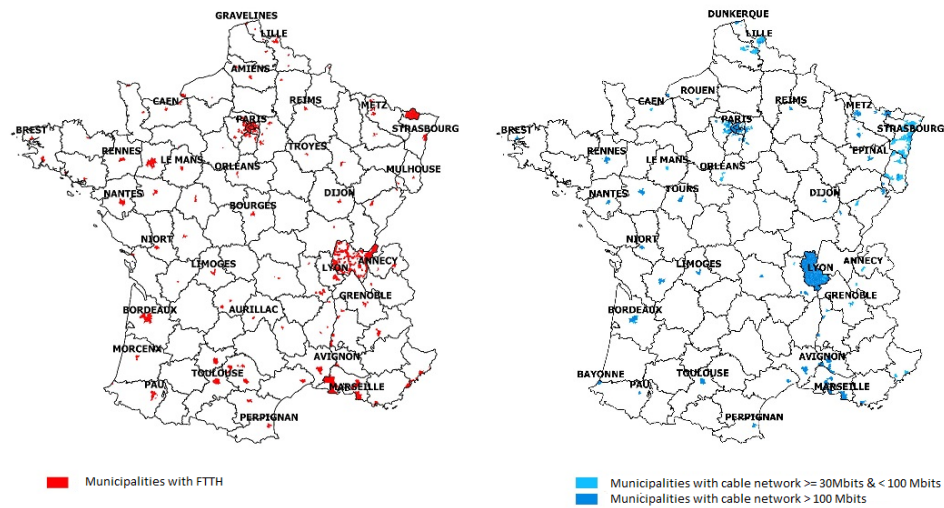
The number for cable in year 2011 is extrapolated because there were no cable upgrades reported in this year.

Table B.1: LLU entry in municipalities by SFR, Free and other operators.

	SFR	Free	Other	Total
2010	6,404	8,487	6,509	12,826
2011	7,739	10,727	7,435	15,295
2012	9,586	12,894	7,922	17,367
2013	13,025	16,103	8,219	20,876
2014	14,140	19,488	8,610	23,215

Number of municipalities in which SFR, Free and other operators entered via LLU out of a total of 36,104 municipalities.

Figure B.2: Coverage by fiber (FTTH) and upgraded cable in metropolitan France as of September 2014.



Source: ARCEP.

Table B.2: Fiber entry in municipalities by Orange, SFR and Free and cable upgrade by Numericable.

	Orange	SFR	Free	Total	Numericable
2010	126	97	94	138	202
2011	197	158	102	208	202
2012	298	219	103	307	329
2013	456	348	106	465	700
2014	588	425	106	596	1,068

Number of municipalities in which Orange, SFR and Free deployed fiber (FTTH) and Numericable upgraded its cable network out of total of 36,104 municipalities.



Table B.3: Description of variables.

Variable Name	Description	Years	Source
Nb fiber	Number of fiber operators in municipality	2010-2014	Orange, SFR website, Free users' website
Nb LLU	Number of LLU operators in municipality	2010-2014	Orange
Cable	Presence of upgraded cable (dummy)	2010-2014	Numericable website
VDSL	Presence of VDSL lines (dummy)	2010-2014	Orange
Co-investment	Co-investment by Orange and SFR (dummy)	2010-2014	Orange, SFR websites
ADSL before 2000	ADSL launch before 2000 (dummy)	2010-2014	Orange
Households	Number of households (in thousand)	2008-2012	INSEE
Density	Number of households per surface (thousand/km <sup>2</sup> )	2008-2012	INSEE
Share flats	Percentage of flats (%)	2008-2012	INSEE
Income	Average annual income (in thousand Euros)	2010-2014	DGFIP

Table B.4: Summary statistics (years 2010-2014).

Variable	Obs.	Mean	Std. Dev.	Min	Max
Orange fiber	180,520	0.009	0.096	0	1
SFR fiber	180,520	0.007	0.083	0	1
Free fiber	180,520	0.003	0.053	0	1
Nb fiber	180,520	0.019	0.206	0	3
Nb LLU	180,520	0.886	1.028	0	6
LLU	180,520	0.496	0.500	0	1
Cable	180,520	0.014	0.117	0	1
VDSL	180,520	0.071	0.256	0	1
Co-investment	180,520	0.004	0.059	0	1
ADSL before 2000	180,520	0.071	0.256	0	1
Households	180,520	0.744	3.524	0.001	100
Density	180,520	0.076	0.464	0.00	21.84
Share flats	180,520	0.089	0.141	0	1.00
Income	180,520	23.334	6.337	5.0	157.3

The number of households in municipality was truncated by 100 thousand due to few extreme cases.

Table B.5: LLU entry in municipalities.

Variables	Model I	Model II
Loghh	0.445*** (0.009)	0.379*** (0.012)
Logdensity	0.805*** (0.013)	0.608*** (0.018)
Logdensity_2012	0.022 (0.014)	0.029 (0.020)
Logdensity_2013	0.062*** (0.014)	0.116*** (0.019)
Logdensity_2014	0.040*** (0.013)	0.018 (0.021)
Logincome	1.826*** (0.029)	1.398*** (0.041)
Share flat	-0.971*** (0.060)	-1.031*** (0.086)
ADSL before 2000	1.275*** (0.025)	0.590*** (0.038)
Year 2012	0.346*** (0.053)	0.270*** (0.078)
Year 2013	1.021*** (0.053)	1.245*** (0.076)
Year 2014	1.279*** (0.052)	0.858*** (0.082)
$\mu^1$	2.160*** (0.118)	-3.140*** (0.167)
$\mu^2$	3.397*** (0.118)	-2.084*** (0.168)
$\mu^3$	6.895*** (0.120)	1.158*** (0.169)
$\mu^4$	9.451*** (0.123)	2.677*** (0.172)
Sunk cost		5.813*** (0.031)
Regional dummies	Yes	Yes
Observations	144,416	144,416
LL	-129771	-66517

Model I: without sunk costs. Model II: with sunk costs.

Table B.6: LLU entry thresholds.

(1) Without sunk costs				
Year	Entrant 1	Entrant 2	Entrant 3	Entrant 4
2011	233	626	10,284	79,465
2012	177	467	7319	54,612
2013	118	304	4370	30,643
2014	88	229	3455	25,073
(2) With sunk costs				
Year	Entrant 1	Entrant 2	Entrant 3	Entrant 4
2011	1186	3462	92,571	432,070
2012	909	2574	62,734	280,338
2013	459	1197	22,667	90,003
2014	473	1356	34,190	155,236

Predictions based on models from Table B.5.

The entry thresholds represent an average across all municipalities of a minimum size of local market, which is required to accommodate a given number of LLU operators. Panel (1) shows entry thresholds without sunk costs. Panel (2) shows entry thresholds with sunk costs.

Table B.7: Fiber entry in municipalities.

	Model I: Full sample			Model II: Sub-sample		
	(1)	(2)	(3)	(1)	(2)	(3)
Nb LLU	0.674*** (0.092)	0.844*** (0.104)	0.540*** (0.180)	0.669*** (0.092)	0.821*** (0.103)	0.553*** (0.181)
VDSL	-0.338*** (0.121)	-0.181 (0.126)	-0.661*** (0.195)	-0.311** (0.121)	-0.132 (0.123)	-0.661*** (0.196)
Cable	0.515*** (0.130)	0.681*** (0.144)	0.713*** (0.216)	0.470*** (0.131)	0.622*** (0.145)	0.667*** (0.217)
Co-investment		3.327*** (0.183)			3.625*** (0.199)	
Loghh	1.204*** (0.094)	0.856*** (0.107)	2.996*** (0.240)	1.147*** (0.096)	0.706*** (0.105)	2.901*** (0.240)
Logdensity	1.740*** (0.233)	2.071*** (0.268)	2.945*** (0.340)	1.950*** (0.265)	2.389*** (0.313)	3.458*** (0.374)
Logdensity_2011	-0.264 (0.178)	-0.240 (0.195)	-0.314 (0.295)	-0.407** (0.200)	-0.399* (0.231)	-0.574* (0.331)
Logdensity_2012	-0.798*** (0.203)	-0.838*** (0.226)	-1.093*** (0.280)	-0.990*** (0.228)	-1.095*** (0.267)	-1.471*** (0.318)
Logdensity_2013	-1.219*** (0.209)	-1.429*** (0.233)	-1.689*** (0.279)	-1.367*** (0.239)	-1.643*** (0.278)	-2.006*** (0.319)
Logdensity_2014	-1.303*** (0.210)	-1.594*** (0.234)	-1.874*** (0.278)	-1.448*** (0.241)	-1.813*** (0.280)	-2.189*** (0.319)
Logincome	0.730*** (0.237)	0.794*** (0.251)	2.260*** (0.570)	0.589** (0.249)	0.506* (0.265)	1.888*** (0.582)
Share flat	1.490*** (0.410)	1.961*** (0.462)	5.050*** (1.100)	1.305*** (0.411)	1.667*** (0.463)	4.044*** (1.090)
ADSL before 2000	1.032*** (0.160)	0.831*** (0.177)	3.203*** (0.389)	1.021*** (0.160)	0.847*** (0.177)	3.011*** (0.382)
Year 2011	1.140*** (0.171)	1.034*** (0.185)	2.559*** (0.315)	1.300*** (0.199)	1.212*** (0.221)	2.839*** (0.344)
Year 2012	2.054*** (0.202)	1.720*** (0.219)	4.246*** (0.320)	2.252*** (0.235)	1.938*** (0.261)	4.580*** (0.350)
Year 2013	2.910*** (0.229)	2.131*** (0.246)	6.321*** (0.366)	3.105*** (0.263)	2.302*** (0.291)	6.671*** (0.393)
Year 2014	3.417*** (0.244)	2.444*** (0.262)	7.479*** (0.400)	3.617*** (0.277)	2.601*** (0.307)	7.846*** (0.427)
$\mu^1$	10.013*** (0.891)	9.357*** (0.963)	26.715*** (2.330)	9.450*** (0.936)	8.023*** (1.008)	24.688*** (2.338)
$\mu^2$	10.810*** (0.892)	10.534*** (0.976)	28.448*** (2.346)	10.255*** (0.937)	9.246*** (1.023)	26.438*** (2.353)
$\mu^3$	13.261*** (0.923)	13.432*** (1.027)	35.023*** (2.443)	12.800*** (0.969)	12.391*** (1.083)	33.191*** (2.443)
$\sigma$			21.679*** (2.118)			20.287*** (1.983)
Regional dummies	yes	yes	yes	yes	yes	yes
Observations	180,520	180,520	180,520	70,820	70,820	70,820
LL	-3660	-3129	-2768	-3547	-2962	-2685

The sub-sample includes only municipalities with population greater than 250 households, and excludes Paris and cities which represent a single municipality with population above 100,000 (i.e., Bordeaux, Lille, Montpellier, Nantes, Nice, Rennes, Strasbourg and Toulouse). Specification (1): base model specification. Specification (2): with co-investment. Specification (3): with random effects.

Table B.8: Fiber entry thresholds: random effects estimation.

(1) Base: with LLU competitors, cable and VDSL			
Year	Entrant 1	Entrant 2	Entrant 3
2010	58,382	76,881	222,316
2011	40,218	54,428	174,872
2012	32,397	46,347	184,498
2013	23,132	34,582	163,142
2014	17,961	27,328	137,984
(2) Without LLU competitors			
Year	Entrant 1	Entrant 2	Entrant 3
2010	61,844	81,440	235,499
2011	42,996	58,187	186,951
2012	35,228	50,398	200,622
2013	25,854	38,651	182,333
2014	20,221	30,767	155,345
(3) Without LLU competitors, cable and VDSL			
Year	Entrant 1	Entrant 2	Entrant 3
2010	62,743	82,623	238,921
2011	43,681	59,114	189,929
2012	36,037	51,555	205,226
2013	24,435	36,530	172,328
2014	18,697	28,449	143,640

Predictions based on specification (3) of Model II in Table B.7 for a sub-sample of municipalities. The entry thresholds represent an average across all municipalities of a minimum size of local market, which is required to accommodate a given number of fiber operators. Panel (1) shows entry thresholds with LLU competitors, cable and VDSL. Panel (2) shows entry thresholds without LLU competitors, but with cable and VDSL. Panel (3) shows entry thresholds without LLU competitors, cable and VDSL.

## Appendix C: Additional Tables

Table C.1: Number of municipalities in which Orange and SFR co-invest in fiber as of 2014.

	High density	Other	Total
Orange alone	141	154	295
SFR alone	122	10	132
Orange-SFR co-investment	1	292	293

Number of high-density and other municipalities in which in 2014 Orange and SFR invested in fiber alone and co-invested, out of total of 36,104 municipalities. The single high-density municipality in which Orange and SFR co-invested is Poitiers. ARCEP includes it among densely populated areas due to practical considerations.

Table C.2: Summary statistics by the number of fiber entrants in municipality in 2014.

Nb fiber	Obs.	Density	Households	Share flats	VDSL	Nb LLU	Cable	Income
0	35,508	0.04	0.47	0.08	0.21	1.15	0.02	24,584
1	172	0.98	10.39	0.51	0.76	3.21	0.34	28,836
2	327	1.48	15.68	0.60	0.79	3.32	0.48	27,891
3	97	5.93	36.23	0.87	0.93	3.90	0.86	31,316

Table C.3: Summary statistics by the number of LLU entrants in municipality in 2014.

Nb LLU	Obs.	Density	Households	Share flats	VDSL	Nb fiber	Cable	Income
0	12,889	0.01	0.15	0.05	0.04	0.00	0.00	22,133
1	6687	0.02	0.24	0.06	0.23	0.00	0.01	23,758
2	13941	0.06	0.67	0.10	0.33	0.00	0.03	26,543
3	1941	0.35	3.52	0.26	0.51	0.26	0.15	29,181
4	617	1.58	11.07	0.45	0.68	0.85	0.42	29,,921
5+	29	0.60	17.65	0.37	0.86	0.79	0.41	26,750

Table C.4: LLU entries and exits between periods.

	Nb LLU <sub>t</sub>					
Nb LLU <sub>t-1</sub>	0	1	2	3	4	5
0	67,092	8820	2121	19	0	0
1	509	17,208	8228	95	1	0
2	61	561	30,298	806	10	0
3	1	13	240	6268	426	2
4	0	0	4	79	1488	30
5	0	0	0	0	4	31
6	0	0	0	0	0	1

Change in the number of LLU operators in municipalities between two consecutive periods for all observations in years 2011-2014. We lack information on the change in the number of LLU entrants between years 2009-2010. The total number of observations is 144,416. Observations on the diagonal represent no change in the number of operators between two periods, observations above the diagonal represent entries and below the diagonal are exits.

Table C.5: Fiber entries and exits between periods.

	Nb fiber <sub>t</sub>			
Nb fiber <sub>t-1</sub>	0	1	2	3
0	178,806	193	285	14
1	0	248	48	15
2	0	0	506	68
3	0	0	0	337

Change in the number of fiber operators in municipalities between two consecutive periods for all observations in years 2010-2014. The total number of observations is 180,520. Observations on the diagonal represent no change in the number of operators between two periods, observations above the diagonal represent entries and below the diagonal are exits.

Table C.6: The number of fiber entries and the identity of fiber operators.

Nb. of entries	Orange	SFR	Free	Total
0	0	0	0	178,785
1	407	16	20	441
2	824	797	57	839
3	434	434	434	434

The number of observations (municipalities in years 2010-2014) with a different number of fiber entries and the identity of fiber operators.



Table C.7: Fiber entry in municipalities: alternative specifications.

	Model I: Fiber/cable entry			Model II: Without VDSL: years 2010-2012			Model III: Orange entry	
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(3)
Nb LLU	0.426*** (0.058)	0.448*** (0.061)	0.241** (0.103)	0.642*** (0.179)	0.571*** (0.208)	1.387*** (0.436)	0.725*** (0.099)	2.821*** (0.476)
VDSL	-0.596*** (0.073)	-0.525*** (0.075)	-0.479*** (0.110)				-0.377*** (0.141)	-1.199** (0.571)
Cable				0.978*** (0.191)	1.094*** (0.203)	1.739*** (0.467)	0.430*** (0.133)	2.383*** (0.722)
Co-investment		2.945*** (0.141)			2.897*** (0.228)			
Loghh	0.813*** (0.063)	0.637*** (0.064)	1.358*** (0.119)	1.070*** (0.122)	0.879*** (0.134)	3.127*** (0.388)	1.394*** (0.100)	7.473*** (0.525)
Logdensity	1.034*** (0.100)	1.274*** (0.109)	1.804*** (0.139)	1.436*** (0.216)	1.517*** (0.232)	3.024*** (0.469)	1.385*** (0.218)	5.862*** (0.898)
Logdensity_2011	0.201*** (0.040)	0.182*** (0.041)	0.317*** (0.100)	-0.201 (0.155)	-0.180 (0.162)	-0.396 (0.300)	-0.357* (0.214)	-1.913** (0.874)
Logdensity_2012	-0.160** (0.075)	-0.267*** (0.079)	0.024 (0.088)	-0.667*** (0.172)	-0.701*** (0.181)	-1.194*** (0.298)	-0.807*** (0.223)	-3.543*** (0.915)
Logdensity_2013	-0.374*** (0.084)	-0.568*** (0.089)	-0.044 (0.087)				-1.032*** (0.223)	-3.997*** (0.914)
Logdensity_2014	-0.655*** (0.088)	-0.864*** (0.092)	-0.633*** (0.085)				-0.968*** (0.220)	-3.481*** (0.901)
Logincome	1.099*** (0.147)	1.266*** (0.161)	1.258*** (0.317)	0.765** (0.305)	0.663** (0.293)	2.839*** (0.815)	1.211*** (0.257)	6.176*** (1.403)
Share flat	0.654*** (0.237)	0.736*** (0.248)	2.147*** (0.551)	1.912*** (0.647)	2.416*** (0.708)	5.120*** (1.781)	1.772*** (0.451)	13.177*** (2.444)
ADSL before 2000	0.779*** (0.089)	0.659*** (0.093)	2.353*** (0.202)	1.332*** (0.328)	1.355*** (0.329)	3.086*** (0.704)	1.029*** (0.166)	7.039*** (0.822)
Year 2011	0.392*** (0.048)	0.310*** (0.045)	0.885*** (0.131)	1.061*** (0.148)	0.933*** (0.157)	2.677*** (0.343)	1.328*** (0.199)	7.443*** (1.128)
Year 2012	1.043*** (0.073)	0.795*** (0.070)	2.221*** (0.131)	1.859*** (0.172)	1.516*** (0.183)	4.377*** (0.380)	2.369*** (0.218)	13.291*** (1.307)
Year 2013	2.186*** (0.099)	1.681*** (0.099)	4.461*** (0.159)				3.476*** (0.245)	19.891*** (1.564)
Year 2014	2.303*** (0.113)	1.700*** (0.113)	4.406*** (0.169)				4.256*** (0.267)	24.677*** (1.786)
$\mu^1$	7.609*** (0.585)	7.537*** (0.645)	13.921*** (1.217)	10.246*** (1.111)	9.550*** (1.130)	30.058*** (3.689)		
$\mu^2$	9.200*** (0.588)	9.445*** (0.654)	17.259*** (1.227)	10.959*** (1.109)	10.432*** (1.133)	31.807*** (3.734)		
$\mu^3$	10.610*** (0.602)	11.161*** (0.684)	20.404*** (1.241)	12.720*** (1.139)	12.388*** (1.177)	36.778*** (3.901)		
$\mu^4$	12.103*** (0.610)	12.557*** (0.686)	24.756*** (1.282)					
Constant							-14.833*** (1.026)	-82.431*** (6.488)
$\sigma$			17.891*** (1.036)			24.814*** (4.248)		4.921*** (0.081)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	180,520	180,520	180,520	108,312	108,312	108,312	180,520	180,520
LL	-9917	-9345	-7532	-1401	-1288	-1141	-2135	-1503

Model I: includes cable operator among fiber entrants. Model II: estimated for years 2010-2013 without VDSL. Model III: estimated for Orange entry only. Specification (1): base model specification. Specification (2): with co-investment. Specification (3): with random effects.