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Abstract

In this paper, we study the impact of competition on the legacy copper network on the deployment of high-speed broadband. We first develop a theoretical model, which shows that the relation between the number of competitors and investment in a quality-improving technology can be positive if the quality of the new technology is high enough, and is negative otherwise. We test these theoretical predictions using data on broadband deployments in France in more than 36,000 local municipalities. First, using panel data over the period 2011-2014, we estimate a model of entry into local markets by alternative operators using local loop unbundling (LLU). Second, using cross-sectional data for the year 2015, we estimate how the number of LLU entrants impacts the deployment of high-speed broadband, controlling for the endogeneity of LLU entry. We find that a higher number of LLU competitors implies lower incentives to deploy and expand coverage of fast broadband, with speed of 30Mbps or more. By contrast, a higher number of local competitors has a positive effect on the incentive to deploy super-fast broadband, with speed of 100Mbps or more, but has no significant effect on the incentive to expand coverage of this technology.

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

Keywords: high-speed broadband, local loop unbundling, competition, market entry.

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1 Introduction

The deployment of next-generation broadband access networks, capable of delivering high-speed Internet access, is seen as an important driver of economic and social development. High-speed broadband infrastructures are expected to stimulate growth and job creations, through increased productivity and by stimulating innovation in products and services.[1]

Europe however lags behind other regions, in particular the US, in terms of deployment of next-generation access networks, which has raised concerns from policymakers.[2] Some (incumbent) telecommunications operators blame an overly competitive landscape in Europe, which, they argue, has eroded operators' margins, and as a consequence, their ability to invest in new infrastructures.[3] By contrast, alternative operators contend that it is competition that drives investment.[4]

Competition in broadband markets in Europe has developed via liberalization and the introduction of a specific regulatory provision, "local loop unbundling" (LLU), a policy that enables alternative operators to lease wholesale access to the incumbents' legacy copper network to offer broadband Internet access services to consumers. While local loop unbundling was abandoned in the US in 2005, in Europe it has been a cornerstone of the regulation of broadband markets over the last ten years.

The local loop unbundling regulation in Europe was implemented in the early 2000's,[5] and led to a wave of entry of alternative operators in local markets, offering broadband services to residential and business consumers through the DSL ('Digital Subscriber Line') technology.

In this paper, we study how the number of LLU entrants in a local market, which has resulted from this entry wave, affects today the incentives of broadband service providers to roll out next-generation access network infrastructures ('NGA networks'). The impact of the number of local competitors on investment incentives is *a priori* ambiguous. On the one hand, a higher number of LLU operators delivering DSL services, and hence a more competitive local broadband market,

[1]See Röller and Waverman (2001), Czernich, Falck, Kretschmer and Woessmann (2011) and Ahlfeldt, Koutroumpis and Valletti (2017), among others, for empirical evidence on the positive impact of telecommunications infrastructures, and in particular broadband infrastructures, on growth and jobs.

[2]For a comparative study of broadband deployment in Europe and in the US, see, e.g., Yoo (2014).

[3]For example, in a report for ETNO, the professional association of incumbent operators, BCG (2013) states that: "network owners are hindered in capturing the fair returns needed to fund investments, primarily because of over- and inconsistent regulation."

[4]For example, ECTA, which is the professional association of incumbent operators, argues that "sustainable competition is what drives efficient investment" (ECTA, 2017).

[5]Regulation (EC) No 2887/2000 of the European Parliament on unbundling.

reduces the expected profits from offering NGA services, and therefore the incentive to invest (a profitability effect). On the other hand, a higher number of LLU competitors implies lower pre-investment profits from existing broadband operations. The opportunity cost of investment (foregone *ex-ante* profits), which corresponds to Arrow's famous 'replacement effect' (Arrow, 1962), is thus lower, which increases the incentive to invest. Which of these two effects dominates is *a priori* unclear.

We start by developing a simple theoretical model to study the impact of the number of competitors using an old technology (in our context, basic broadband) on a firm's incentive to invest in a quality-improving new technology (the NGA network technology). We show that the relative impact of the number of competitors on the profitability of the investment and on the replacement effect depends on the quality improvement brought by the new technology, compared to the old technology. Using a specific model of competition with quality differentiation, we find that if the quality improvement is sufficiently high, the relation between the number of competitors and the investment incentive is positive, and that otherwise it is negative.

We test these theoretical predictions using a comprehensive data set on the market structure and the deployment of high-speed broadband in local municipalities in France. We adopt a two-step empirical approach, which allows us to estimate the impact of the local market structure on the deployment of high-speed broadband, controlling for the endogeneity of market structure.

In the first step, we build a model of entry of alternative operators in local municipalities via local loop unbundling. We estimate this entry model using panel data on the number of LLU entries and exits in 36,104 municipalities over the period 2011-2014. We find that local market characteristics, such as the size of the market and the density of population, are important determinants of LLU entry. We also find significant sunk costs which represent a barrier to entry, though entry becomes easier over time.

In the second step of our empirical approach, we estimate how the number of LLU operators in a municipality affects the deployment of high-speed broadband. To do so, we use a cross-sectional data set for the second quarter of 2015 on the coverage of different speed tiers in municipalities. We control for the endogeneity of LLU entry by means of a control function approach, using our model of LLU entry estimated at the first step of the analysis. We also take into account local market characteristics such as market size, population density and income, and the heterogeneity in local market conditions.

We find that a higher number of LLU competitors has a negative impact on the deployment and coverage of fast broadband, delivering speeds of 30Mbps or more. By contrast, the presence of ultrafast broadband in a municipality, with speeds of 100Mbps or more, is positively affected by the number of LLU operators. However, we find no significant impact of the number of LLU competitors on the share of population in the municipality covered with this new technology.

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

2 Literature Review

2.1 Theory

Bourreau, Cambini and Doğan (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 pre- and post-investment profits, and hence, influences investment incentives through different channels. As a consequence, a lower access price for copper implies less investment incentives for the entrant, and has an ambiguous effect on the investment incentives of 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 take access regulation as given, and analyze the impact of the market structure of local markets on investment. Our paper is thus also related to the broad theoretical literature on the impact of market structure on investment and innovation.[6] Since the firms that invest in new broadband infrastructures earn *ex-ante* profits from the old broadband technology, we are more specifically interested in the impact of market structure on the profit incentive, defined as the difference between post- and pre-investment profits. Arrow (1962) shows that the profit incentive under monopoly is lower than under perfect competition, due to a "replacement effect" for the monopolist; as a consequence, the monopolist has less incentives to invest or innovate than firms

[6] See Gilbert (2006) for a survey of the theoretical and empirical literature on this topic.

under competition. Yi (1999) and Belleflamme and Vergari (2011) extend Arrow's analysis to oligopolistic markets, and study how the profit incentive varies with the number of competitors. 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 relationship between the profit incentive and the number of firms can be non-monotonic.

We contribute to this literature by studying the relation between the profit incentive and the number of firms for *vertically* differentiated products. In Section 3, we show that the relation between the profit incentive and the number of firms depends on the level of quality differentiation.

2.2 Empirics

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

First, our paper is related to the literature on entry into local telecommunications markets. This literature was mainly focused on the US market before the Federal Communications Commission (FCC) changed its decision on the open access policy in 2004 (see Greenstein and Mazzeo, 2006; Economides, Seim and Viard, 2008; Xiao and Orazem, 2011; Goldfarb and Xiao, 2011; Wilson, Xiao and Orazem, 2018). Recently, Nardotto, Valletti and Verboven (2015) have used UK data in the years 2005-2009 to estimate entry into local markets by alternative LLU operators. In another recent paper, Skiti (2016) uses local market data in New York State to analyze the entry and technology deployment decisions of cable and fiber operators. He provides evidence that cable incumbents made strategic investments in high-speed broadband technology to deter fiber entry. Wilson (2016) uses nationwide US data to estimate a dynamic oligopoly model, and shows that public investment in infrastructure crowds out investment from private firms more than it induces them to invest preemptively. In the first part of our empirical analysis, we use data from France in the years 2011-2014 to estimate a model of entry by LLU operators, which is similar to Nardotto et al. (2015).

Second, our paper contributes to the literature on investment in next-generation access

(NGA) fiber networks. In this stream of literature, a few papers have studied the effect of access regulation on the migration from copper to fiber networks (see, e.g., Bacache, Bourreau and Gaudin, 2014; Briglauer, 2015; Briglauer, Cambini and Grajek, 2018). In particular, Briglauer et al. (2018) 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. However, these studies use country-level data, and as such they cannot account for the large within-country differences in market structure and NGA investments that we observe in our micro-level data.

Only two papers in this strand of literature rely on local market information. Minamihashi (2012) uses municipal-level data for Japan in years 2005-2009 and finds that the LLU regulation imposed on the Japanese incumbent operator has discouraged entrants to deploy 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 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. All these papers study the impact of access regulation on NGA investments, whereas our focus is different: we study the impact of market structure and competition on investments in NGA networks.

Finally, our paper is related to the literature on the impact of market structure on quality competition between Internet Service Providers. Nardotto et al. (2015) show that LLU entry had a positive impact on the quality of the DSL services provided by entrants (i.e., download speed) in the UK, because of their efforts to differentiate from the incumbent. Prieger, Molnar and Savage (2015) study how DSL firms respond to increased competition in terms of quality of broadband (speed) in a thousand local markets in California in years 2011-2013. They show that incumbent DSL firms increase the quality of their products when a cable operator enters a local market and starts offering fast broadband, or when a competing operator deploys fiber in the market. Wallsten and Mallahan (2013) use data on US residential broadband subscriptions and speeds and find that the number of fixed providers in a census area is positively correlated with the highest available broadband speeds. In a similar vein, Molnar and Savage (2017) show that competition has a positive effect on speed. Based on data for a sample of 5,281 census block groups (CBGs) in the US in 2011, they analyze the relationship between market structure and product quality, and show that the broadband speed is higher in markets with two or more competing firms, compared to markets with a single firm.

We contribute to this literature by using a comprehensive data set on the market structure and the provision of fast and super-fast broadband at the municipality level in France, and by offering evidence on the impact of LLU competition on the provision of different speed tiers in a municipality.

3 A Model of Investment in Network Quality

In this section, we develop a stylized model of investment in network quality, which allows us to derive theoretical predictions on the impact of the number of LLU competitors on quality investment by network operators.

Model. A network operator, firm 0, contemplates upgrading its network in a given municipality with a new technology (e.g., next-generation broadband access), which offers a higher quality of service compared to the old technology (e.g., DSL broadband), for an investment cost of C.

Prior to investment, firm 0 operates an old-technology network, and faces competition from $n \geq 1$ identical firms, indexed with $i = 1, ..., n$, which also use the same old technology. In the context of the broadband market, we can interpret the n rival firms as LLU competitors. We denote the quality of the old technology by s_O, and the quality of the new technology by s_N, with $s_N > s_O$. We assume that the new technology is not a "drastic" innovation that replaces the old technology, which is consistent with what we observe in the broadband market.

For a given number of competitors n, let $\pi^O_{\text{pre}}(n, s_O)$ denote firm 0's pre-investment profit with the old technology O, and $\pi^N_{\text{post}}(n, s_N, s_O)$ its post-investment profit with the new technology N. We assume that firm 0's post-investment profit increases with the level of quality improvement, that is, $\partial\pi^N_{\text{post}}/\partial s_N \geq 0$. We assume furthermore that a higher number of firms in the market intensifies competition and lowers profits, that is, $\partial\pi^O_{\text{pre}}/\partial n \leq 0$ and $\partial\pi^N_{\text{post}}/\partial n \leq 0$.

Impact of market structure on investment. Firm 0's incentive to invest in the new technology is given by the difference in profit that the firm can earn if it invests in the new technology 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 $PI \equiv \pi_{\text{post}}^{N}(n, s_N, s_O) - \pi_{\text{pre}}^{O}(n, s_O)$. Firm 0 decides to deploy the new network technology in the municipality if and only if $PI \geq C$.

We are interested in how the number of local competitors affects firm 0's incentive to invest in the new network technology. We thus study how the number of rivals affects its profit incentive:

$$\frac{\partial PI}{\partial n} = \underbrace{\frac{\partial \pi_{\text{post}}^{N}}{\partial n}}_{\text{(-)}} - \underbrace{\frac{\partial \pi_{\text{pre}}^{O}}{\partial n}}_{\text{(-)}}. \tag{1}$$

Equation (1) shows that the effect of the number of competitors on firm 0's profit incentive depends on two opposite effects. First, more intense competition reduces the profitability of the investment ($\partial \pi_{\text{post}}^{N}/\partial n \leq 0$), and therefore reduces investment incentives. Second, when the local market is more competitive, the opportunity cost of investment in terms of foregone (pre-investment) profits is reduced ($\partial \pi_{\text{pre}}^{O}/\partial n \leq 0$), which increases firm 0's investment incentive.

The impact of the local market structure on firm 0's investment incentive is thus *a priori* ambiguous. Which effect dominates is going to depend in particular on the quality of the new technology, s_N, and on the variation of the marginal effect of the number of firms on the profit incentive, $\partial PI/\partial n$, with respect to the level of quality s_N, i.e., $\partial^2 PI/\partial n \partial s_N = \partial^2 \pi_{\text{post}}^{N}/\partial n \partial s_N$.

If $\partial^2 \pi_{\text{post}}^{N}/\partial n \partial s_N \leq 0$ for all n and s_N, then $\partial PI/\partial n \leq 0$ for all n and s_N. Indeed, at $s_N = s_O$, we have $PI = 0$ and thus $\partial PI/\partial n = 0$. Since $\partial PI/\partial n$ decreases with s_N, the profit incentive is always (weakly) decreasing in the number of firms.

By contrast, if $\partial^2 \pi_{\text{post}}^{N}/\partial n \partial s_N \geq 0$ for some n and s_N, then we can have $\partial PI/\partial n \geq 0$ for some n and s_N, in which case the profit incentive increases with the number of firms. For example, at the extreme, if the new technology replaces the old one (i.e., it is "drastic"), then we have $\partial^2 \pi_{\text{post}}^{N}/\partial n \partial s_N = 0$ and the profit incentive increases with the number of competitors.

This discussion suggests that the number of competitors may have a positive effect on the incentive to invest if the quality of the new technology is sufficiently high. We propose below an illustrative model where this is indeed the case.

An illustrative model. We adopt the model of quantity competition with quality differentiation of Katz and Shapiro (1985), which has often been used in the literature to model competition in the broadband market.[7]

The indirect utility of a consumer of type τ is $U_i = \tau + s_i - p_i$, where s_i and p_i denote the quality and price of firm $i = 0, ..., n$. Consumers' types are uniformly distributed over $(-\infty, 1]$.[8] Firms compete in quantities and the marginal cost is normalized to zero. Firms $i = 1, ..., n$ offer quality $s_i = s_O$, whereas firm 0 offers quality $s_0 = s_O$ before investing and $s_0 = s_N$ after investing. We assume that $s_N < 1+2s_O$, which ensures that the firms that use the old technology remain active when the new technology is deployed.

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:

$$\pi^O_{\text{pre}}(n, s_O) = \left(\frac{1 + s_O}{n + 2}\right)^2.$$

The post-investment equilibrium profits are:

$$\pi^O_{\text{post}}(n, s_N, s_O) = \left(\frac{1 + 2s_O - s_N}{n + 2}\right)^2$$

for firms $i = 1, ...n$ and

$$\pi^N_{\text{post}}(n, s_N, s_O) = \left(\frac{1 + s_N + n(s_N - s_O)}{n + 2}\right)^2$$

for firm 0. Firms' profits decrease with the number of competitors, and firm 0's post-investment profit increases with the level of quality s_N, as assumed in the general model.

The following proposition characterizes the impact of the number of competitors on firm 0's incentive to invest in the new technology.

Proposition 1. *In the Katz & Shapiro illustrative model, firm 0's incentive to invest in the new technology 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*

[7] See, for example, Foros (2004) and Bourreau et al. (2012).

[8] Allowing for negative values of τ avoids corner solutions where all consumers purchase one of the firms' products.

of competitors.

Proof. We have $\partial PI/\partial n \geq 0$ if and only if

$$s_N \geq 1 + 2s_O - \frac{1+s_O}{n+1}. \tag{2}$$

Note that condition (2) is compatible with our assumption that $s_N < 1 + 2s_O$.

For a given number of competitors n, if s_N is sufficiently high to that (2) holds strictly, a small increase in the number of competitors leads to higher investment incentives. Note though that when n becomes large, (2) may not hold. If (2) does not hold for a given number of competitors n, an increase in the number of competitors leads to lower investment incentives. □

In our framework, this result suggests that if the new hgih-speed broadband technology brings a sufficiently high quality improvement for consumers over the old broadband technology (i.e., DSL), then we might expect a *positive* relationship between the number of LLU competitors and investment in high-speed broadband. Otherwise, if the quality improvement is less significant, we should expect a *negative* relationship. The intuition is that a high level of quality improvement softens the impact of local competition on post-investments profits (when (2) holds, we have indeed $\partial^2\pi^N_{\text{post}}/\partial n \partial s_N > 0$), due the strong vertical differentiation between the old and the new technologies.

To test these theoretical predictions, we use micro-level data on competition and investment in the broadband market in France, as we explain below.

4 Industry Background

4.1 The Broadband Market in France

Broadband connections provide consumers with high-speed access to the Internet.[9] In France, four main wireline technologies are used to deliver broadband: digital subscriber line (DSL), 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),

[9]The European Commission defines broadband as Internet connections with speed of at least 144 kbps.

cable modem 6.6%, and optical fiber 3.6%.[10]

DSL is a family of technologies used to transmit data over traditional copper telephone wires, which connect customer premises to the main distribution frames (MDFs) of the historical incumbent operator (France Telecom/Orange in France). 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.[11] To provide DSL services to consumers, an operator wishing to use LLU ('LLU operator' hereafter) has to build a backhaul network to the MDFs, and then install its DSL equipment in the MDFs to deliver broadband over copper lines.

The LLU regulation led to a wave of entry of operators in various local municipalities. Table 2 in the Appendix shows the number of municipalities in which operators have LLU presence for the years 2011-2014. 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.[12]

The cable modem is a technology that enables broadband over coaxial cables, which were originally developed to carry television signals. There is only one cable operator in France, Numericable, which covers about 30% of the population, mainly in urban areas. In 2007, Numericable started to upgrade its cable network using the DOCSIS 3.0 standard, which permits high-bandwidth data transfers substantially exceeding those of DSL connections. Since 2007, Numericable has not deployed new cable infrastructure.

VDSL is a DSL technology providing faster transmission speeds than standard DSL, but only for very short copper lines.[13] The deployment of VDSL was authorized by the French regulator,

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[10] 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.

[11] 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.

[12] 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, Herault Telecom, Ariege Telecom, Haut Rhin Telecom, Colt, Rennes Metropole Telecom, Alliance Connectic and a number of other very small operators.

[13] 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

ARCEP, in October 2013.[14] VDSL is deployed by the main DSL operators (Orange, Free and SFR).

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 those achievable with the DSL or cable modem technologies. In France, from 2010 onwards, the main DSL operators (Orange, SFR and Free) started to roll out fiber-to-the-home (FTTH) networks.[15] Fiber networks are expected to replace copper networks at least in densely populated areas.[16]

We adopt the European Commission's definitions for the different broadband speed tiers: basic broadband refers to a connection with download speed below 30Mbps, fast broadband to a connection of 30Mbps or more, and ultra-fast broadband to a connection of 100Mbps or more. In France, basic broadband is provided using the DSL technology by the incumbent Orange and LLU entrants (SFR, Free and a competitive fringe). Fast broadband 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. Finally, super-fast broadband is available in the areas where DOCSIS 3.0 and/or FTTH has been deployed.

Table 1 summarizes the definitions of basic, fast and ultra-fast broadband. In the paper, we define *high-speed broadband* as fast or ultra-fast connections.[17]

Broadband category	Speed	Technology
Basic	$<$ 30Mbps	DSL, cable modem, VDSL, fiber
Fast	$\geq$ 30Mbps	Cable modem, VDSL, fiber
ultra-fast	$\geq$ 100Mbps	Cable modem, fiber

Table 1: Definition of basic, fast and ultra-fast broadband.

lines.

[14]In 2013, the authorization to implement VDSL concerned only lines in direct distribution, i.e, lines directly connected to a MDF. In October 2014, ARCEP authorized the deployment of VDSL to all eligible lines, i.e., all lines connected to a street cabinet.

[15]The FTTH technology is also called fiber-to-the-premises (FTTP).

[16]Note that currently in France there is no regulation imposing access to fiber infrastructure, i.e., there is no unbundled or bitstream access to fiber networks.

[17]This is consistent with the focus in the European Union on fast and ultra-fast broadband. This is also consistent with the current definition by the FCC of high-speed broadband, that is, fixed broadband connections delivering speeds of at least 25Mbps download and 3Mbps upload. See Federal Communications Commission, "2018 Broadband Deployment Report", FCC 18-10.

4.2 Data Sets

We use three data sets, which are available at the municipal level: (i) a data set on the identity and the number of active LLU operators in municipalities; (ii) a data set on the share of the local population with access to Internet speeds of at least 3Mbps, 8Mbps, 30Mbps and 100Mbps; and (iii) a data set with socio-economic information on municipalities.

The first data set, which we received from the fixed copper-line incumbent operator Orange, contains information on the presence of LLU operators at the municipality level. For each municipality in Mainland France and each year between 2011-2014, we observe the presence and identity of LLU operators. In the municipalities where the local loop has been unbundled, there are between one and five LLU operators. Table 6 in Appendix shows that there is a large number of entries and exits by LLU firms in France in the time period considered.

Our second data set provides information on the share of population in every municipality in Mainland France with access to Internet connections with speeds of at least 3Mbps, 8Mbps, 30Mbps and 100Mbps, based on different technologies: DSL, VDSL, cable modem and fiber. We obtained this information from the Observatory of High-Speed Internet in France, which is a government initiative collecting broadband coverage information from local authorities and operators at the municipal level and on a quarterly basis. The objective of the Observatory is to track the development of high-speed Internet in France. The data set is publicly available, and the first period is the second quarter of 2015.[18] The information on speed represents the maximum download speed that the line can actually reach, and was computed using data provided by network operators. As a result, the information provided may differ from the speeds reported by different Internet service providers in the context of their business practices. In addition, the actual speed depends on other factors, such as modem, traffic congestion, etc.

Our third 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 municipal-level data on the population size (defined as the number of households), population density (defined as the number of households divided by the geographic area 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 also do not have access to recent statistics, we consider that they make their entry decisions based on demographic information with a two-

[18] Source: `http://www.francethd.fr/`.

year lag. In addition, we have information on the average household income per municipality in the years 2010-2014, which was retrieved from the website of the General Direction of Public Finance (DGFIP). Table 4 in the Appendix describes the variables used in the analysis.

These different data sets were merged using the unique INSEE code for each municipality. After merging, we have information on 36,104 municipalities in France for the years 2011-2014, resulting in a total of 144,416 observations.[19] The statistics on coverage by broadband speed is available only from 2015 onwards. Thus, we merge the coverage data in 2015 with the other information in 2014. There should be no drastic difference in coverage between the end of 2014 and the second quarter of 2015. We lose 78 municipalities when merging the coverage data with LLU entry data and end up with 36,026 observations for 2015. Table 5 reports summary statistics for the variables used in the analysis. The availability of detailed local data on LLU operators and coverage with high-speed broadband allows us to estimate the models at the municipal level.

5 Econometric Models

In this section, we present the econometric models. First, we set up a model of LLU entry, which allows us to estimate the determinants of entry decision together with sunk costs. Next, we introduce a reduced-form model of broadband coverage, in which we take into account the endogeneity of LLU entry through a control function approach. Finally, we extend the model of broadband coverage to account for sample selection.

5.1 LLU Entry

To begin with, we set up a model of LLU entry to analyze the demand-side and supply-side factors that influence entry. A firm is going to enter a given local market via LLU to offer DSL broadband services to residential and/or business consumers. The firm enters the local market if, and only if, its expected gross profits in the area outweigh the entry costs. There are substantial fixed costs of entry into local markets. As discussed in Section 4, a firm wishing to enter a local market via LLU has to build a backhaul network to the incumbent's MDF, and

[19]There were 36,192 municipalities in France in the year 2014. Due to administrative changes in the years 2011-2014, we removed from the data 88 small municipalities. Some municipalities were also split into two and others merged, which led to changes in their names and INSEE codes.

then co-locate its DSL equipment in the MDF.

In the previous literature on entry into broadband markets, both Xiao and Orazem (2011) for the US and Nardotto et al. (2015) for the UK consider the investments made by LLU operators to be mostly sunk. The identification of sunk costs is based on a comparison of entry thresholds for markets where entry took place with thresholds for markets where there was no entry. The sunk costs imply that less demand is needed for an incumbent to continue operations than is needed to support a new entrant.

We assume that at the end of each time period firms decide whether to enter into 'new' local markets in the next period and whether to continue their 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 that we consider does not allow for simultaneous entry and exit.

The number of LLU entrants in municipality i at time t is denoted as $N_{it} = n \in \{0, 1, 2, 3+\}$, where 3+ refers to three entrants or more.[20] The discounted future profits of a firm facing n competitors in market i at time t can be written as:

$$\bar{\pi}_{it}^{n} = \alpha_t lnS_{it} + X_{it}\beta_t - \mu^n + \epsilon_{it} \equiv \pi_{it}^{n} + \epsilon_{it}, \tag{3}$$

where S_{it} is the market size approximated by the number of households and X_{it} is a vector of other characteristics of municipalities, which are potential determinants of profits (including income, population density, and the share of flats in the total number of premises). We interact selected characteristics with time, as denoted by β_t. We also consider that firms' profits may differ across geographic regions due to other factors, which we approximate by a set of regional dummy variables.[21] In addition, we include a set of dummy variables for the year in which ADSL was deployed in a municipality for the first time, since municipalities in which ADSL was deployed earlier were open to LLU entry for a longer period of time. Finally, μ^n represents the negative effect on profits from the n^{th} firm, and ϵ_{it} is the error term which has a standard normal

[20]Since there is only a small number of markets with more than three entrants, we truncate the number of entrants to three.

[21]Until 1 January 2016, there were 22 regions in France. In 2014, the French parliament passed a law reducing the number of metropolitan regions to 13; it has been effective since 1 January 2016.

distribution. 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).

Profits, π_{it}^{n}, are not observed and represent a latent variable. They include the non-sunk part of fixed costs. Apart from that firms have sunk costs, SC, which cannot be recovered when they exit. The model of entry that we consider does not account for heterogeneity between firms, which is problematic because firms may have different cost structures. There are firms of different sizes and different geographic presence. Moreover, the main LLU operators, SFR and Free, deploy fiber networks and provide mobile services, which cannot be offered by smaller LLU entrants.

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 gross profits from entry must exceed the sunk cost of entry. But for the $(n+1)^{th}$ marginal firm, the gross profits must be lower than the sunk cost, which can be expressed as follows:

$$\textbf{Case 1, net entry: } N_{it} > N_{it-1} \text{ if } \bar{\pi}_{it}^{n} \geq SC \text{ and } \bar{\pi}_{it}^{n+1} < SC. \tag{4}$$

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 $N_{it} = N_{it-1}$. The n^{th} marginal firm stays in the market, because its expected discounted profits from continuation exceed 0. But for the $(n+1)^{th}$ marginal firm, the benefit from entry is lower than the sunk cost, which can be specified as:

$$\textbf{Case 2, inaction: } N_{it} = N_{it-1} \text{ if } \bar{\pi}_{it}^{n} \geq 0 \text{ and } \bar{\pi}_{it}^{n+1} < SC. \tag{5}$$

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. Once this firm has exited the market, the n^{th} marginal firm expects positive profits, which can be expressed as:

$$\textbf{Case 3, net exit: } N_{it} < N_{it-1} \text{ if } \bar{\pi}_{it}^{n} \geq 0 \text{ and } \bar{\pi}_{it}^{n+1} < 0. \tag{6}$$

Using the profit specification (3), the above inequalities can be combined to derive the probability of observing $N_{it} = n$ entrants in market i at time t:

$$Pr(N_{it} = n) = \Phi(\pi_{it}^{n} - SC \cdot I_{it}^{+}) - \Phi(\pi_{it}^{n+1} - SC \cdot (I_{it}^{+} + I_{it}^{0})), \tag{7}$$

where $\Phi(.)$ 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:

$$\hat{\theta} = \arg\max \sum_{i=1}^{M} \sum_{t=1}^{T} \sum_{n=0}^{N} y_{it}^{n} \ln(Pr(N_{it} = n|\theta)), \tag{8}$$

where y_{it}^{n} takes value of 1 if $N_{it} = n \in \{0, 1, 2, 3+\}$, and 0 otherwise.

5.2 Deployment of High-Speed Broadband

We now introduce a model of deployment of high-speed Internet access. As mentioned in Section 4, basic broadband is defined as a connection with download speed below 30Mbps, fast broadband as a connection of 30Mbps or more, and ultra-fast broadband as a connection of 100Mbps or more. We then define high-speed broadband as a fast or ultra-fast connection. To deliver high-speed broadband, operators have to upgrade their networks. DSL operators upgrade their networks to VDSL and/or fiber, while the cable operator, Numericable, upgrades its network to the DOCSIS 3.0 technology. The deployment of new broadband technologies takes place in parallel and is endogenously determined. First, the three operators deploying fiber (Orange, SFR and Free) can strategically respond to upgrades of the cable network to high-speed broadband. They may also decide to deploy VDSL instead of fiber. At the same time, Numericable can decide to upgrade its network as a strategic response to fiber or VDSL deployment by Orange, SFR and Free. The deployment of high-speed broadband is also affected by competition from LLU operators offering slower DSL services based on the copper network.

We abstract from modeling the strategic decisions of operators in this complex environment, and estimate a reduced-form equation for the share of population in a given municipality with access to different connection speeds:

$$y_i = \delta N_i + \gamma Z_i + u_i, \tag{9}$$

where y_i denotes the share of population in municipality i with access to a connection with speed of at least 3Mbps, 8Mbps, 30Mbps and 100Mbps; N_i denotes the number of LLU entrants in the municipality; and Z_i is a set of control variables that may determine coverage, including demand and cost shifters. Since the information on coverage starts in the second quarter of 2015, we estimate the model for a single cross-section of municipalities in this year, with the right-hand side variables for the end of 2014. The municipal characteristics included in the estimation are the same as in the model of LLU entry, except for the set of dummy variables for the year of launching DSL in a municipality. The early launch of DSL in more attractive municipalities led to a higher number of LLU entrants, but there should not be a direct impact on the deployment of high-speed broadband. Table 7 shows the average number of LLU operators in 2014 for different years of launching DSL services in a municipality.

Model (9) is first estimated using ordinary least squares (OLS), with a set of municipal characteristics and dummy variables for regions. In this regression, the LLU entry variable may be correlated with the error term u_i. If there is a persistent shock in the municipality with a positive impact on high-speed broadband coverage, it may also positively impact the LLU entry. For instance, local authorities may decide to reduce administrative costs and burdens to stimulate LLU competition and foster the deployment of high-speed broadband. We account for this using our model of LLU entry, which we discuss above. More specifically, we account for endogeneity of the number of LLU entrants, N_i, using the control function approach proposed by Manuszak and Moul (2008). This approach was also used by Nardotto et al. (2015) to estimate the impact of LLU on broadband penetration in the UK.

Assuming that the error terms of the LLU entry and high-speed broadband coverage models (ϵ_{it} and u_i) are multivariate normally distributed, one can show that:

$$\begin{aligned} E(y_i|X_i, N_i, S_i, Z_i) &= \delta N_i + \gamma Z_i + E(u_i|N_i = n, S_i, X_i), \\ &= \delta N_i + \gamma Z_i + \sigma_{u\epsilon} h(N_i, S_i, X_i; \theta), \end{aligned} \tag{10}$$

where $\theta = (\alpha, \beta, \mu^n)$ is the parameter vector from the entry model, $\sigma_{u\epsilon}$ is the covariance between

u_i and ϵ_i, and $h(N_i, S_i, X_i; \theta)$ is the inverse Mills ratio (see Nardotto et al. (2015)):

$$\begin{aligned} h(N_i, S_i, X_i; \hat{\theta}) &\equiv E(\epsilon_i | \hat{\pi}_i^n - \hat{SC} \cdot I_i^+ < \epsilon_i < \hat{\pi}_i^{n+1} - \hat{SC} \cdot (I_i^+ + I_i^0)) \\ &= \frac{\phi(\hat{\pi}_i^n - \hat{SC} \cdot I_i^+) - \phi(\hat{\pi}_i^{n+1} - \hat{SC} \cdot (I_i^+ + I_i^0))}{\Phi(\hat{\pi}_i^n - \hat{SC} \cdot I_i^+) - \Phi(\hat{\pi}_i^{n+1} - \hat{SC} \cdot (I_i^+ + I_i^0))}. \end{aligned} \tag{11}$$

The error term u_i in the coverage equation (9) can be decomposed into the sum of two terms and written as $u_i = \sigma_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}) + \varepsilon_i$, where by construction ε_i is mean zero conditional on N_i , S_i, X_i and Z_i. The coverage equation (9) can then be rewritten as follows:

$$y_i = \delta N_i + \gamma Z_i + \sigma_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}) + \varepsilon_i. \tag{12}$$

First, we estimate the model of LLU entry using the maximum likelihood estimator (8). Then, we use the estimates to compute the correction term $h(N_i, S_i, X_i; \hat{\theta})$, which is used as an additional variable in the coverage regression (12). The control function approach needs to satisfy the exclusion restrictions. We need at least one variable which determines entry of LLU operators, but is not correlated with the error term in the coverage equation for high-speed broadband. As we discussed above, the set of dummy variables for the year of launching DSL services in a municipality should satisfy this condition. However, even though DSL launch in a municipality should not directly impact the deployment of high-speed broadband, it may be correlated with omitted municipality-specific characteristics. To mitigate this issue, we use in the estimation a set of municipality characteristics and regional dummy variables.

5.3 Sample selection

When estimating equation (12), we need to take into account a potential sample selection problem. In the majority of municipalities, fast and ultra-fast broadband is not deployed at all, and hence there is no broadband coverage with speed of at least 30Mbps or 100Mbps. We take this into account by estimating Heckman's sample selection model in two stages (see Heckman (1979)). In the first stage, we estimate a sample selection equation by means of a probit model:

$$y_i^* = \delta_s N_i + \gamma_s W_i + \sigma_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}) + \upsilon_i, \tag{13}$$

where y_i^* takes value of 1 for municipalities with some coverage, and 0 otherwise. The vector of estimated parameters is denoted by $\varphi = (\delta_s, \gamma_s, \sigma_{u\epsilon})$. In the second stage, the modified coverage equation is estimated for the sample of municipalities with positive coverage:

$$y_i = \delta_c N_i + \gamma_c Z_i + \sigma_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}) + \sigma_{v\varepsilon} \lambda(N_i, W_i, h_i; \hat{\varphi}) + e_i. \tag{14}$$

In equation (14) we use the fact that the error term ε_i in equation (12) can be decomposed into the sum of two terms, $\varepsilon_i = \sigma_{\varepsilon v} \lambda(N_i, W_i, h_i; \hat{\varphi}) + e_i$, where by construction e_i is mean zero conditional on N_i, S_i, X_i, Z_i and W_i. The hazard function (inverse Mills ratio), denoted by $\lambda(N_i, W_i, h_i; \hat{\varphi})$, is computed using the first-stage probit estimates:

$$\lambda_i(N_i, W_i, h_i; \hat{\varphi}) = \frac{\phi(\hat{\delta} N_i + \hat{\gamma} W_i + \hat{\sigma}_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}))}{\Phi(\hat{\delta} N_i + \hat{\gamma} W_i + \hat{\sigma}_{u\epsilon} h(N_i, S_i, X_i; \hat{\theta}))}. \tag{15}$$

To satisfy the exclusion restrictions, we need at least one variable which determines the presence of high-speed broadband in a municipality and is included in W_i, but which does not impact coverage and is not correlated with the error term e_i in the coverage equation (14). In the probit estimation, we include the number of households in the municipality and the total population in the department to which this municipality belongs. More populous municipalities are more attractive for deploying high-speed broadband, but these variables should not affect the share of population covered. In other words, the share of population covered with high-speed broadband may be comparable in smaller and larger municipalities, conditional on the presence of high-speed broadband operators in these municipalities.

6 Estimation Results

6.1 LLU Entry

Table 8 shows the estimation results for the model of LLU entry using panel data for 36,104 municipalities over the period 2011-2014. Model I is estimated without sunk costs (the ordered probit model), while Model II allows for non-zero sunk costs. Based on the much lower value of the log-likelihood function, the preferred model is Model II. The estimation results show the presence of significant sunk costs, which represent a barrier to entry and play an important role in broadband markets.[22]

We find that market size and density of the population significantly and positively affect LLU entry. In the estimation, we use time dummies and interact them with population density to determine whether it becomes easier over time to enter less densely populated areas. The interaction terms are insignificant, but the coefficients of the time dummies increase over time. Overall, entry becomes easier over time and we observe more entry in smaller municipalities. This may be due to technological progress and declining costs of equipment, and/or due to the introduction of specific regulations, which reduced the wholesale costs of LLU for alternative operators.[23] Furthermore, we find that a higher level of income has a positive impact on LLU entry, indicating a higher demand for broadband in richer municipalities. The share of flats in the total number of residences is significant and negative, which implies that there is less LLU entry in markets with a larger share of flats. This result may be explained by a high share of flats in municipalities with social housing, and hence, it may be also related to income effects. Apart from that, municipalities in which DSL was launched earlier experience more LLU entry, which is also shown in Table 7. Finally, we include in the estimation a set of regional dummy variables which are highly significant. They control for other factors determining the attractiveness of municipalities which belong to the same regions.

To sum up, our estimation results confirm the role of market size and other local market characteristics in determining the number of LLU entrants. We use the estimates from Model II to compute the correction term given by equation (11), which we use in the second-stage regressions for high-speed broadband coverage.

6.2 Deployment of High-Speed Broadband

Table 9 shows the estimation results for the share of population with access to fast (at least 30Mbps) and ultra-fast (at least 100Mbps) broadband, based on any technology that can deliver these speed levels (i.e., VDSL, cable or fiber). Table 10 shows the estimation results for the share of population with access to at least 3Mbps and 8Mbps. These models are estimated

[22]Xiao and Orazem (2011) and Nardotto et al. (2015) also find significant sunk costs in the US and UK markets, respectively.

[23]For example, in January 2012, the LLU wholesale price was slightly reduced by ARCEP from €9 to €8.80. In 2011, there was also a change in the regulation of bitstream access (the removal of the obligation of cost orientation for bitstream access in areas with wholesale competition), after which operators may have favored LLU over bitstream access.

using a cross-section of 36,026 municipalities in the second quarter of 2015. We estimate four regressions for each speed level: (i) the OLS model given by equation (12) with and without the correction term for the number of LLU entrants; and (ii) Heckman's sample selection model given by equation (14) with and without LLU correction term.[24]

In the OLS regressions for all four speed tiers, the number of LLU operators has a significant and negative impact on the share of population with access to broadband in a municipality (OLS I). When the correction term from the LLU model is included in the estimation, the magnitude of the impact increases for all four regressions (OLS II). The LLU correction term is significant and positive in all regressions, except for the speed tier of 100Mbps or more. The positive estimates of the covariance between the error terms, $\sigma_{u\epsilon}$, indicate that, conditional on other market characteristics, high broadband coverage is observed in markets that are more likely to support a greater number of LLU operators. Thus, unusually attractive demand conditions in a municipality encourage both LLU entry and higher broadband coverage, and consequently, the OLS estimates of the impact of LLU competition on broadband coverage suffer from an omitted variable bias. To correct for this bias, we need to include in the regressions the correction term, $h(N_i, S_i, X_i; \hat{\theta})$, with the exception of the regression for ultra-fast broadband coverage. Our corrected OLS results suggests that competition on the copper network reduces incentives to deploy fast and super-fast broadband.

However, in the majority of municipalities fast and ultra-fast broadband is not deployed at all, which we need to take into account by estimating Heckman's sample selection model. First, we estimate how the number of LLU operators impacts the presence in a municipality of technologies which offer speed above a certain threshold by means of a probit model (selection equation). Then, we use the uncensored observations and include the inverse Mills ratio computed from the probit model in an OLS regression to estimate how the number of LLU operators impacts the share of population in a municipality with access to speed above a certain threshold (coverage equation). The number of uncensored observations for each speed tier are shown in Tables 9 and 10. The first model which we estimate does not include the LLU correction term (Heckman I),

[24] As an alternative approach, we used observations on all municipalities to estimate a Tobit model, where the high-speed coverage variable y_i is censored at zero for municipalities without coverage. Both Heckman's sample selection and Tobit models are closely related. The first model is less restrictive in that the parameters explaining the censoring are not constrained to equal those explaining the variation in the observed dependent variable. Furthermore, Heckman's model depends on the assumed normal distribution of the error terms in the first stage regression, while Tobit model also relies on normality assumption of the error term. Both methods are inconsistent when this assumption is violated. The estimation results based on Tobit models are comparable.

while the second model includes it (Heckman II). When the correction term is included, it is insignificant for ultra-fast broadband, but significant and positive for the other speed tiers, in both the selection and coverage equations. This is analogous to what we have obtained for the OLS regressions, and it indicates that not accounting for the LLU correction term results in an omitted variable bias, except for ultra-fast broadband coverage. We thus focus our discussion on the results for Heckman's model with the LLU correction term included.

In Heckman's sample selection model for speeds of 100Mbps or above, the number of LLU entrants is insignificant in the coverage equation, but significant and positive in the selection equation. The inverse Mills ratio is positive and significant at the 10% significance level, which indicates that the error terms in both equations are correlated, and so unusually attractive demand conditions in a municipality encourage both the presence of ultra-fast broadband providers and greater coverage. After inclusion of both correction terms, $h(N_i, S_i, X_i; \hat{\theta})$ and $\lambda(N_i, W_i, h_i; \hat{\varphi})$, we find that the number of LLU competitors does not have any significant impact on coverage of ultra-fast broadband. By contrast, the market presence of ultra-fast broadband is positively stimulated by competition on the copper network. This result contrasts with our results for the OLS regressions, with and without LLU correction term, in which we found a significant and negative effect. But the number of 1,353 observations used in the second stage regression is rather small. The results for Heckman's sample selection model for speeds above 30Mbps are similar to those obtained with the OLS regressions. After inclusion of the two correction terms, we find a significant and negative impact of the number of LLU operators on both coverage and market presence of fast broadband.

Our estimation results thus suggest that the impact of the number of LLU competitors on investment in high-speed broadband in a municipality, in terms of presence and coverage, depends on the level of quality brought by the new broadband technologies deployed. For intermediate levels of quality (30Mbps or more), we find a negative relationship between the number of LLU competitors and the presence and coverage of the new (fast broadband) technology. By contrast, for high levels of quality (100Mbps or more), we find a positive relationship between the number of LLU competitors and the presence of the new (super-fast broadband) technology, but we find no significant effect on coverage.

These results are consistent with the model developed in Section 3, where we showed that the impact of the number of competitors on the incentives to upgrade from an old to a new technology is positive if the level of quality brought by the new technology is sufficiently high, and negative otherwise. In light of our theoretical model, our estimation results for speeds of 100Mbps or more could be explained by the strong vertical differentiation between ultra-fast and basic broadband, which softens the impact of LLU competition on the profits of ultra-fast broadband providers, while at the same time intense LLU competition decreases the opportunity cost of investment. As the profitability of ultra-fast broadband operations is hardly affected by the number of LLU competitors, we then find a positive relation between the number of LLU competitors and investment incentives.

The estimation results for speeds of 3Mbps or more and 8Mbps or more show the impact of LLU competition on the incentives to deploy *any* broadband technology in municipalities, since these speed levels can be delivered with the "old" DSL technology, and not only with the "new" VDSL, upgraded cable and fiber technologies.

In Heckman's sample selection model for speeds of 8Mbps or above, we find a negative impact of LLU competition on both market presence and coverage by technologies which offer this speed level. The inclusion of the LLU correction term leads to a larger (negative) impact of LLU competition on both market presence and coverage. These results are similar to those obtained with the OLS regressions. The results for the low broadband speed of 3Mbps or more are a bit different. While the impact of LLU competition on coverage is also negative after inclusion of the two correction terms, the impact on the market presence of technologies with this speed level is insignificant (without the LLU correction term, the impact is positive and significant).

On the basis of these results, we can conclude that LLU competition leads to lower coverage also in the speed range between 3Mbps and 30Mbps. This suggests that neither the incumbent nor the LLU entrants have an incentive to invest to expand their DSL coverage with higher speed levels.

We include in the models a number of socio-economic variables to account for the heterogeneity of local markets, which have a significant impact on the deployment of high-speed broadband. In Heckman's model, high-speed broadband is more likely to be present in more populous municipalities, for all speed levels. It is also more attractive to deploy ultra-fast broadband (speeds of 100Mbps or more) in municipalities which are located in bigger departments in terms of total population. For all speed levels, both the presence and the coverage of broadband is greater in municipalities with a higher density of population. This is consistent with the idea that in general, it is cheaper and more profitable to deploy high-speed broadband in densely populated areas. The share of flats in the total number of residences has a positive impact on coverage for all speed levels. This suggests that there are lower costs of deploying high-speed broadband in areas with many apartment blocks. Furthermore, we find that a higher level of income has a positive impact on the presence of high-speed broadband in municipalities. We also include in the estimations a set of regional dummy variables to control for differences in attractiveness of municipalities which belong to them, which are in general significant. The estimates of municipality characteristics in Heckman's and OLS models are comparable, with some differences with respect to the significance and sign of the income variable.

7 Conclusion

In this paper, we analyze the impact of local market competition on the legacy copper network on the deployment of high-speed broadband. We develop a theoretical model and show that the relation between the number of local competitors and investment in a quality-improving technology such as high-speed broadband can be positive if the quality of the new technology is high enough, and is negative otherwise. We test these theoretical predictions using data on broadband deployment in local municipalities in France. First, we use panel data on 36,104 municipalities in France over the period 2011-2014 to estimate a model of entry into local markets by alternative operators via local loop unbundling (LLU). Second, we estimate how the number of operators that have entered a local market via LLU impacts the deployment of high-speed broadband, using cross-sectional data on 36,026 municipalities in year 2015, and controlling for the endogeneity of LLU entry.

Our empirical results suggest that the relation between the degree of competition in local markets (approximated by the number of LLU competitors) and investment in high-speed broadband depends on the level of quality improvement brought by the new broadband technologies. We find that a higher number of LLU competitors implies lower incentives to deploy and expand coverage of fast broadband, that is, broadband with speed of 30Mbps or more. By contrast, we find a positive relation between the number of local competitors and the incentive to deploy super-fast broadband, that is, broadband with speed of 100Mbps or more. However, we find no significant relation between the number of competitors and the coverage of super-fast broadband in the municipality.

We find that local market characteristics also affect investment incentives. The presence of high-speed broadband in a municipality is positively influenced by its market size, population density and the income level, while coverage is positively influenced by the density of population and the level of income. Thus, investment in high-speed broadband is also driven by demand factors and declining costs of deployment.

Due to the particularities of the broadband market and data constraints, we were only able to model the deployment of high-speed broadband in a reduced-form setting. In future research, when the broadband industry in France develops further and the coverage by fiber networks expands, one may attempt to model a more advanced discrete entry game.

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Appendix: Figures and Tables

Table 2: LLU entry in municipalities by SFR, Free and other operators.

Year	SFR	Free	Other	Total
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.

Table 3: Number of LLU entries in municipalities by year.

Nb LLU	2011	2012	2013	2014
0	20,809	18,737	15,228	12,889
1	6,750	6,503	6,662	6,687
2	6,441	8,624	11,885	13,941
3	1,766	1,829	1,731	1,941
4	336	407	569	617
5	2	4	29	29
Total	36,104	36,104	36,104	36,104

Table 4: Description of variables.

Variable Name	Description	Years	Source
Coverage	Share of population covered with 3Mbps+, 8Mbps+, 30Mbps+, 100Mbps+	Q2 2015	France THD
Nb LLU	Number of LLU operators in municipality	2010-2014	Orange
ADSL launch year	ADSL launch year in municipality	2010-2014	Orange
Households	Number of households (in thousand)	2008-2012	INSEE
Population department	Population in department (local authority) (in thousand)	2008-2012	INSEE
Population density	Number of households per km^2 (thousand/km^2)	2008-2012	INSEE
Share flats	Percentage of flats (%)	2008-2012	INSEE
Income	Average annual income (in thousand Euros)	2010-2014	DGFIP

Table 5: Summary statistics for 2010-2014.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Nb LLU	144,416	0.96	1.04	0	5
LLU	144,416	0.53	0.50	0	1
Households (tsd)	144,416	0.75	3.53	0	100
Population department (tsd)	144,416	668	478	77	2,834
Population density (tsd/km2)	144,416	76	464	0	21,835
Income	144,416	0.09	0.14	0.00	1.00
Share flats	144,416	19,497	3,090	4,815	45,463
ADSL after 2005	144,416	0.12	0.32	0	1
ADSL 2005	144,416	0.20	0.40	0	1
ADSL 2004	144,416	0.25	0.43	0	1
ADSL 2003	144,416	0.14	0.35	0	1
ADSL 2002	144,416	0.07	0.26	0	1
ADSL 2001	144,416	0.15	0.36	0	1
ADSL before 2000	144,416	0.07	0.26	0	1
Coverage 3Mbps	36,026	0.61	0.40	0	1
Coverage 8Mbps	36,026	0.45	0.41	0	1
Coverage 30Mbps	36,026	0.14	0.26	0	1
Coverage 100Mbps	36,026	0.02	0.13	0	1
Presence 3Mbps	36,026	0.83	0.38	0	1
Presence 8Mbps	36,026	0.71	0.45	0	1
Presence 30Mbps	36,026	0.31	0.46	0	1
Presence 100Mbps	36,026	0.04	0.19	0	1

The number of households in a municipality was truncated to one hundred thousand due to a few extreme cases.

Table 6: LLU new entrants and exits between periods.

	Nb LLU_t					
Nb LLU_{t-1}	0	1	2	3	4	5
0	67,092	509	61	1	0	0
1	8,820	17,210	561	13	0	0
2	2,121	8,228	30,298	240	4	0
3	19	95	806	6,268	79	0
4	0	1	10	426	1,488	4
5	0	0	0	2	30	32

Change in the number of LLU operators in municipalities between two consecutive periods for all observations in years 2010-2014. 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 7: Number of LLU new entrants in 2014 by year of launching ADSL services in a municipality.

ADSL launch	mean	std. dev.	min	max
1999	3.22	0.86	0	4
2000	2.56	0.96	0	5
2001	1.90	0.86	0	5
2002	1.63	0.74	0	5
2003	1.57	0.75	0	4
2004	1.04	0.87	0	4
2005	0.45	0.71	0	4
2006	0.24	0.59	0	5
2007	0.33	0.62	0	4
2008	0.63	0.86	0	2
2009	0.22	0.52	0	2
2010	0.31	0.62	0	2
2011	0.34	0.54	0	2
All	1.19	1.04	0	5

Based on the sample of 36,104 municipalities.

Table 8: LLU entry in municipalities.

Variables	Model I	Model II
Log households	0.145***	0.119***
	(0.005)	(0.007)
Log pop density	0.440***	0.305***
	(0.008)	(0.010)
Log pop density $\times$ 2012	0.010	0.004
	(0.008)	(0.012)
Log pop density $\times$ 2013	0.003	-0.002
	(0.008)	(0.011)
Log pop density $\times$ 2014	-0.009	-0.003
	(0.008)	(0.012)
Log income	0.662***	0.522***
	(0.018)	(0.023)
Share flats	-0.240***	-0.443***
	(0.036)	(0.049)
ADSL after 2005	-1.963***	-1.261***
	(0.020)	(0.028)
ADSL 2005	-1.848***	-1.007***
	(0.018)	(0.024)
ADSL 2004	-1.346***	-0.520***
	(0.016)	(0.023)
ADSL 2003	-0.836***	-0.161***
	(0.016)	(0.023)
ADSL 2002	-0.740***	-0.159***
	(0.018)	(0.025)
ADSL 2001	-0.474***	-0.123***
	(0.015)	(0.022)
Year 2012	0.237***	0.136***
	(0.033)	(0.046)
Year 2013	0.540***	0.449***
	(0.033)	(0.045)
Year 2014	0.723***	0.509***
	(0.033)	(0.047)
Cut 1	-0.822***	-2.493***
	(0.073)	(0.097)
Cut 2	-0.002	-1.860***
	(0.073)	(0.097)
Cut 3	2.086***	-0.170*
	(0.074)	(0.097)
Sunk cost		3.011***
		(0.013)
Regional dummies	yes	yes
Observations	144,416	144,146
LL	-115,780	-61,503

Model I: without sunk costs. Model II: with sunk costs.
Significance at * 10%, ** 5%, *** 1% level. t statistics are in parentheses.

Table 9: Coverage with high-speed broadband.

	>100 Mbps						>30 Mbps					
	OLS I	OLS II	Heckman I		Heckman II		OLS I	OLS II	Heckman I		Heckman II	
Variables			Coverage	Presence	Coverage	Presence			Coverage	Presence	Coverage	Presence
Nb LLU	-0.003***	-0.003***	-0.023	0.065**	-0.012	0.070**	-0.010***	-0.016***	-0.044***	0.005	-0.053***	-0.047***
	(0.001)	(0.001)	(0.015)	(0.027)	(0.017)	(0.032)	(0.002)	(0.002)	(0.004)	(0.011)	(0.005)	(0.014)
Log households	-0.002	-0.001		0.248***		0.247***	0.059***	0.061***		0.730***		0.742***
	(0.001)	(0.001)		(0.026)		(0.027)	(0.002)	(0.002)		(0.014)		(0.014)
Log pop department	0.017***	0.017***		0.500***		0.501***	0.010***	0.010***		0.030		0.026
	(0.001)	(0.001)		(0.041)		(0.041)	(0.003)	(0.003)		(0.019)		(0.019)
Log pop density	0.015***	0.015***	0.056***	0.167***	0.051***	0.166***	0.025***	0.027***	0.045***	0.032**	0.048***	0.048***
	(0.001)	(0.001)	(0.015)	(0.026)	(0.015)	(0.026)	(0.002)	(0.002)	(0.004)	(0.014)	(0.004)	(0.014)
Log income	0.017***	0.018***	0.168***	0.503***	0.160***	0.499***	-0.019***	-0.014**	-0.005	0.053	0.003	0.103**
	(0.003)	(0.003)	(0.034)	(0.078)	(0.035)	(0.080)	(0.006)	(0.006)	(0.013)	(0.046)	(0.014)	(0.047)
Share flats	0.174***	0.173***	-0.046	0.713***	-0.042	0.717***	0.189***	0.186***	0.075***	0.857***	0.072***	0.832***
	(0.007)	(0.007)	(0.064)	(0.130)	(0.064)	(0.130)	(0.013)	(0.013)	(0.021)	(0.094)	(0.021)	(0.094)
Correction term LLU		0.001			-0.027	-0.011		0.013***			0.020***	0.110***
		(0.001)			(0.020)	(0.039)		(0.003)			(0.005)	(0.017)
Mills ratio			0.065*		0.065*				0.080***		0.076***	
			(0.037)		(0.037)				(0.008)		(0.008)	
Constant	-0.121***	-0.121***	-0.066	-6.816***	-0.077	-6.819***	0.337***	0.339***	0.578***	0.497**	0.580***	0.499**
	(0.015)	(0.015)	(0.167)	(0.416)	(0.168)	(0.416)	(0.028)	(0.028)	(0.050)	(0.202)	(0.050)	(0.202)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	36,026	36,026	1,353	36,026	1,353	36,026	36,026	36,026	11,196	36,026	11,196	36,026

Significance at * 10%, ** 5%, *** 1% level. t statistics are in parentheses.

Table 10: Coverage with low-speed broadband.

	>8 Mbps						>3 Mbps					
	OLS I	OLS II	Heckman I		Heckman II		OLS I	OLS II	Heckman I		Heckman II	
Variables			Coverage	Presence	Coverage	Presence			Coverage	Presence	Coverage	Presence
Nb LLU	-0.074***	-0.089***	-0.083***	-0.061***	-0.092***	-0.103***	-0.052***	-0.070***	-0.064***	0.037***	-0.077***	-0.003
	(0.003)	(0.003)	(0.003)	(0.011)	(0.003)	(0.013)	(0.003)	(0.003)	(0.002)	(0.012)	(0.003)	(0.015)
Log households	0.112***	0.115***		0.535***		0.544***	0.087***	0.091***		0.480***		0.487***
	(0.003)	(0.003)		(0.013)		(0.013)	(0.003)	(0.003)		(0.015)		(0.015)
Log pop department	0.005	0.004		-0.019		-0.022	0.005	0.004		-0.023		-0.025
	(0.004)	(0.004)		(0.017)		(0.017)	(0.004)	(0.004)		(0.019)		(0.019)
Log pop density	0.065***	0.070***	0.078***	0.112***	0.081***	0.126***	0.075***	0.080***	0.091***	0.109***	0.095***	0.122***
	(0.003)	(0.003)	(0.003)	(0.014)	(0.003)	(0.014)	(0.003)	(0.003)	(0.003)	(0.016)	(0.003)	(0.016)
Log income	0.019*	0.032***	-0.015	0.121***	-0.008	0.156***	0.052***	0.067***	0.021**	0.146***	0.030***	0.176***
	(0.010)	(0.010)	(0.011)	(0.043)	(0.011)	(0.043)	(0.010)	(0.010)	(0.009)	(0.048)	(0.009)	(0.048)
Share flats	0.089***	0.081***	0.245***	0.488***	0.244***	0.474***	0.019	0.010	0.164***	0.757***	0.163***	0.749***
	(0.020)	(0.020)	(0.019)	(0.109)	(0.019)	(0.109)	(0.020)	(0.020)	(0.017)	(0.143)	(0.017)	(0.143)
Correction term LLU		0.034***			0.020***	0.094***		0.040***			0.026***	0.089***
		(0.004)			(0.004)	(0.016)		(0.004)			(0.004)	(0.019)
Mills ratio			-0.098***		-0.105***					-0.051***		-0.061***
			(0.012)		(0.011)					(0.013)		(0.013)
Constant	0.888***	0.893***	1.122***	1.766***	1.123***	1.787***	0.964***	0.970***	1.145***	2.111***	1.148***	2.137***
	(0.045)	(0.045)	(0.042)	(0.188)	(0.042)	(0.188)	(0.044)	(0.044)	(0.035)	(0.212)	(0.035)	(0.212)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	36,026	36,026	25,677	36,026	25,677	36,026	36,026	36,026	29,892	36,026	29,892	36,026

Significance at * 10%, ** 5%, *** 1% level. t statistics are in parentheses.