Estimating the impact of co-investment on Fiber to the Home adoption and competition[☆]

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ABSTRACT

The demand for faster broadband access is a key driver of FTTH adoption and fixed broadband competition, and therefore of co-investment. This paper assesses the effects on FTTH adoption and competition of FTTH co-investment. Co-investment had indeed been endorsed in the European Electronic Communication Code as a relevant option for conciliating investment and competition. This paper contributes to evaluating this policy option by providing detailed empirical estimates of the influence of co-investment on Fiber to the Home (FTTH) adoption and competition in the French fixed broadband market. We combine several French municipality level datasets and use a two-stage control-function approach to correct for the endogeneity of investor entry. We show that the presence of co-investment leads to an increase of 7.9% in FTTH adoption in 2018. Co-investment offers also enhance competition. Co-investment by competitors causes a decrease in Orange, French incumbent operator, total retail broadband market penetration by 5.9% whereas no co-investment by competitors lets Orange's total retail broadband market penetration unchanged. Our findings confirm that co-investment supports the policy objectives of adoption and competition and should be supported by regulation.

1. Introduction

Should telecommunications operators be encouraged to co-invest in Very High Capacity Networks (VHCN), as defined in the new European Electronic Communications Code?[1] This article contributes to answering this question by providing detailed empirical estimates of the influence of co-investment on Fiber to the Home (FTTH) adoption and competition in the French fixed broadband market. Studying the impact of co-investment on FTTH is relevant for the study of VHCN regulation because FTTH access networks satisfy the definition of VHCNs.

Access to the networks of incumbent operators is covered by European telecommunications policy. The 2002 European regulatory framework considered that opening telecom markets to competition required imposing access to the existing physical infrastructure of former monopolies to new entrants. This access obligation is imposed as long as no competitive alternative for this

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[1] Article 2(2)"(2) 'very high capacity network' means either an electronic communications network which consists wholly of optical fiber elements at least up to the distribution point at the serving location, or an electronic communications network which is capable of delivering, under usual peak-time conditions, similar network performance in terms of available downlink and uplink bandwidth, resilience, error-related parameters, and latency and its variation; network performance can be considered similar regardless of whether the end-user experience varies due to the inherently different characteristics of the medium by which the network ultimately connects with the network termination point";

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infrastructure exists. This regulation is designed to encourage investments by alternative operators in assets that complement the existing infrastructure of the incumbent operator. For instance, the unbundling of copper local loop of former telecommunications monopolies, which was imposed by regulation, has allowed alternative operators to invest into their own active access equipment to compete with incumbents on copper-based broadband access services.

However, this access obligation, initially intended to open access for competitors to copper infrastructure, has been extended to new investments in fiber access networks. Nevertheless this access obligation has discouraged investments in assets to replace the existing copper infrastructure. This outcome was not a concern for public authorities from 2000 to 2010 because the existing copper infrastructure was considered sufficient to support demand for broadband access. However, the situation changed after 2010 when it became clear that the copper infrastructure could not indefinitely support the growing demand for faster connections. In addition, statistics revealed that Europe was behind other regions of the world in terms of telecommunications investment per capita. Since then, the debate regarding access regulation has been concentrated on how to incentivize both incumbents and entrants to invest in newly deployed fiber infrastructure. In areas where the business case of broadband access can support several competing parallel infrastructures, deregulation can occur since access is no longer required to safeguard effective competition. Where the business case of broadband cannot support several parallel infrastructures, public authorities face a dilemma:

- The first extreme option is to impose an access obligation with regard to the fiber infrastructure. In the case of FTTH, the new infrastructure will initially be empty. Its utilization will gradually grow and require around a decade to reach its target value. In such circumstances, the economic calculations required to determine the regulated access price to the FTTH infrastructure must rely on long-term forecasts of FTTH future demand and future costs. Hence, the profitability of FTTH for the investing operator will depend on regulators' beliefs regarding the future. Moreover, finding the right price for such regulated access is highly challenging.

- The second extreme option would be the absence of access obligation. This option would not be problematic if infrastructure competition could exist in each part of the fiber network. However, as mentioned before, the business case of fiber services cannot always support several parallel competing infrastructures. For the parts of the network where demand is too low to allow several infrastructures to coexist, the option of no regulation risks posing a threat to effective competition.

Europe has been looking for intermediate solutions between these two extreme and unsatisfactory options, pure access leading to no investment or no access leading to no competition. These intermediate solutions are based on the principle of risk-sharing, through which access seekers are required to share the investment risk of rolling out new networks to gain access to this new infrastructure. The risk-sharing arrangement may take numerous forms such as value, volume or time commitments, or upfront payments, but the clearest form of risk sharing is co-investment: operators competing downstream share the cost of the upstream investment, and all the co-investors receive long-term rights to the newly deployed infrastructure.

Co-investment schemes have been successfully used for the roll-out of FTTH infrastructure in Portugal, Spain and France. In Portugal and Spain, the co-investment schemes are mainly market driven, with the encouragement of the National Regulatory Authority which sometimes uses the threat of regulation to force operators to develop commercial arrangements among themselves. In France, detailed co-investment schemes were designed by the National Regulatory Authority.

Based on these principles and examples, co-investment has been endorsed by European institutions as a relevant option for conciliating investment and competition. Article 76 of the new European Economic Communications Code (EECC) states that an incumbent operator providing its competitors with appropriate forms of co-investment in its newly deployed fiber infrastructure may be exempted from other forms of access obligations, although the market analysis procedure performed by the National Regulatory Authority has concluded that it holds Significant Market Power (SMP). Before its adoption, Article 76 was seriously questioned by National Regulatory Authorities and alternative operators on the basis that it would reduce competition and lead to re-monopolization. Because of these critics, additional and stricter safeguards for competition were introduced in the final version of the article.

The objective of this paper is to empirically assess whether such co-investment schemes lead to the expected outcomes of more adoption and preserved or enhanced competition. We address this issue by providing empirical evidence for the quantitative causal impact of co-investment on the adoption of FTTH networks in France and on the level of competition.

We use a dataset from 2015 to 2018 in the French municipalities belonging to the so-called "ZMD" or "Zones Moins Denses" (translated in English as less dense areas), a part of French territory where the French regulation imposes specific forms of co-investment obligations on operators that roll-out an FTTH infrastructure. It is relevant for policy purposes to analyze empirically the impact of these co-investment obligations on adoption and competition. Indeed, although the co-investment obligations imposed in less dense areas in France result from symmetric regulation and are not voluntary commitment undertaken by the incumbent operator as anticipated in Article 76 of the EECC, they are consistent with the model of co-investment offers that may lead to an absence of further access obligations under Article 76 of the EECC. Article 76 provides that if an NRA, in the context of a market analysis and after having defined a relevant market and qualified an SMP, was at the step of defining remedies on the FTTH of the incumbent operator, it would be obliged by Article 76 to consider the existence of co-investment offers. The fact that such co-investment offers are available as a result of voluntary initiative or as a result of a symmetric regulation is irrelevant in this context. The NRA would have to note whether the conditions for Article 76 to apply are fulfilled and if so, it shall not impose any further remedies beyond co-investment offers (except for the specific cases provided in Article 76 notably concerning specific markets).

Our study is based on the analysis of detailed data on the roll-out of FTTH networks and services in French municipalities from 2015 to 2018.

The speed of FTTH roll-out in the municipalities covered by the study is subject to a strict regulatory obligation of full coverage within 5 years, corresponding to the actual speed of municipality coverage revealed by our data: therefore, FTTH roll-out speed with municipalities can be considered to be exogenous, determined by these coverage obligations.

Our study analyzes the relationship at the municipality level between co-investment, adoption of FTTH service and penetration of Orange retail fixed access services in the municipality as a measure of competition.

Using a two-stage entry model, as developed by Manuszak and Moul (2008), we are able to identify the influence of co-investment occurrence on these variables in these municipalities.

We show that co-investment, where it occurs, increases FTTH adoption by 7.9% of FTTH home passed. We also prove that co-investment offers intensify competition: where Orange rolls-out FTTH, co-investment by competitors decreases Orange's total retail broadband market penetration by 5.9% whereas no FTTH co-investment by competitors leads Orange's retail fixed broadband market penetration to remain unchanged.

The remainder of this paper is organized as follows. Section 2 discusses the relevant literature. Section 3 presents the regulatory framework for FTTH deployment in less dense areas in France, for which data were extracted. Section 4 describes the data used in our study. Section 5 introduces our econometric model and our estimation strategy. Section 6 presents our estimation results for FTTH investment entry determinants, FTTH adoption and French fixed broadband competition. Section 7 concludes.

2. Literature review

Our paper relates to three streams of the literature concerning the economics of telecommunications. One stream analyzes co-investment and more generally, upstream cooperation between downstream competitors. The second stream empirically analyzes the impact of mandatory access regulation in the telecommunications industry. The third stream employs a two-stage control function approach to examine the relationship between market structure and underlying competition results.

The first stream of the literature on upstream cooperation between downstream competitors mostly includes theoretical papers. The paper most closely related to our work is Bourreau, Cambini et al. (2018), which is specifically dedicated to comparing the outcomes of three regulatory regimes that may be imposed on a dominant telecommunications operator: pure co-investment obligations, pure standard access obligations or the superposition of co-investment and standard access obligations. This paper concludes that in terms of total investment and welfare, the regulatory regime of pure co-investment obligation dominates both pure access obligation and access plus co-investment obligations, especially when demand is uncertain. A second relevant reference is the IDEI policy report by Sand-Zantmann (2017) which reviews the theoretical literature concerning upstream cooperation between firms that compete downstream. It notably mentions the seminal article by d'Aspremont and Jacquemin (1988) "Cooperative and Non Cooperative R&D in Duopoly with Spillovers", as well as papers relating more specifically to the telecommunications industry: Cambini and Silvestri (2013) and Inders and Peitz (2014). The general conclusion of Sand-Zantman's review is that investment should benefit only those players incurring a fair proportion of the investment risk. Our paper adds empirical results to this first stream of the theoretical literature on upstream cooperation between downstream competitors.

The second stream of the literature to which our paper relates is the empirical analysis of the impact of telecommunications access regulation on market outcomes. It notably includes the following papers: Briglauer et al. (2018), Cambini and Silvestri (2012) and Jeanjean and Liang (2012). A good review of numerous studies can be found in Vogelsang (2013), particularly, paragraph 2.2.2.4. "Empirical estimates of regulatory effects on investment". The recent working paper Bourreau, Grzybowski et al. (2018) analyzes the impact of the presence of copper and cable alternative operators on entry into local FTTH markets. Our paper adds new results concerning FTTH and co-investment in this second stream of the empirical literature on the impact of access obligation cooperation between downstream competitors.

The third stream of the literature includes papers that introduce structural entry models to address the problem of endogeneity between market structures and outcomes. The more traditional methods of instrumental variables experience difficulty in finding appropriate instruments and proving that they fulfill the exclusion constraint. Recent work, notably Manuszak and Moul (2008), Molnar and Savage (2017), Nardotto et al. (2015), Rosston et al. (2018) and Xiao and Orazem (2011) have overcome this difficulty. The above-mentioned papers employ a two-stage approach in which a model of endogenous market structure provides correction terms for the second-stage price equation. Our paper adds a new application of this methodology.

3. Regulatory framework of FTTH in the ZMD areas covered by private investment

The empirical analysis presented in this paper is conducted in a subset of areas subject to the "ZMD" regulatory framework for FTTH mentioned in the introduction of this paper. It is the subset where coverage is ensured by private investment: the "ZMD-AMII" ("Zone Moins Dense"-"Appel a Manifestation d'Intention d'Investissement"). First, we describe the FTTH regulatory framework imposed in ZMD areas. Second, we explain how the AMII zone of private investment has been defined and the proportion of France that it represents.

3.1. Co-investment regulation for FTTH in ZMD areas

Describing the current FTTH regulatory framework of ZMD areas in France is necessary because this framework imposes the co-investment arrangements. This regulatory framework has been defined by two documents adopted by the French telecommunications regulatory authority, Autorite de Regulation des Communications Electroniques et des Postes (ARCEP):

- Decision 2009-1106 regarding FTTH regulation in very dense areas includes the most populated municipalities designated in Annex I of this decision and represents approximately 17% of the French population (see https://www.arcep.fr/uploads/txgsavis/09_1106.pdf).

- Decision 2010-1312 regarding FTTH regulation in less dense areas, that is, outside very dense areas, corresponds to the rest of France, which represents 83% of the population (see https://www.arcep.fr/uploads/txgsavis/10_1312.pdf).

Here, we summarize only the rules for less dense areas defined in Decision 2010-1312 because they apply to the geographical areas included in our empirical analysis. We have limited our study to these areas because the applicable co-investment rules are in substance consistent with the conditions under which existing co-investment offers shall prevent a National Regulatory Authority from imposing further access remedies to an operator holding a Significant Market Power under Article 76 of the EECC.

In the less dense areas under study, co-investment concerns local technical areas corresponding to a concentration point (“Point de Mutualization” (PM)) and serving at least 1000 customers.

When an operator intends to roll out an FTTH network in a local technical area corresponding to such a PM, it has the obligation to inform other operators and allow them to share ab initio the costs of the investment in exchange for long-term rights to the newly deployed FTTH infrastructure. Operators that decide not to co-invest ab initio can still enter and co-invest a posteriori, but the price of co-investing a posteriori is higher to reward the initial co-investors for the initial risk that they take.

Operators wishing to co-invest in such local area have the opportunity to purchase allotments of 5% of the capacity of the FTTH access network. These operators can start with only 5% and then buy additional allotments of 5% of the capacity if needed to serve their retail customers. Alternatively, these operators can directly purchase larger allotments of 10%, 15% or more if they expect to rapidly gain sufficient customers to utilize such a capacity.

Co-investing by purchasing larger allotments is less expensive in absolute terms than buying a smaller allotment ab initio and then later purchasing larger allotments. This pricing principle has been adopted to reward operators that purchase a larger share of the initial investment risk.

Operators may also rent FTTH access line by line, but then the price is even higher. The economic principles of these co-investment pricing schemes are detailed in the following document adopted by ARCEP, the French regulator:

- Recommendation made on 23 December 2009 on the conditions of co-investment on FTTH infrastructure and on how co-investment opportunities should be priced: https://www.arcep.fr/uploads/txgspublication/RecoARCEP_mutualization_fiber_01.pdf

These FTTH co-investment pricing principles which apply in less dense areas in France are consistent with the conditions imposed in Article 76 and in Annex IV of the EECC on co-investment offers. According to Article 76 EECC, when these conditions are fulfilled, no further access obligations shall be imposed on the incumbent operator even if it holds Significant Market Power. Therefore, although these co-investment obligations in “less dense area” result from symmetric regulations which have been imposed in France independent of any market analysis procedure, they are not without consequence for market analysis procedures, since they lead to the availability of co-investment offers with the appropriate technical and economical characteristics for the application of Article 76. It should be noted that this French FTTH regulation is symmetric: it applies not only to Orange but to all FTTH networks rolled out in France.

3.2. FTTH private investment areas (“AMII areas”)

This subsection describes how the areas for which FTTH investment is insured by private operators (including the incumbent operator Orange) have been defined in France and the proportion of France that they represent.

In January 2011, the French government launched a Call for Expressing Interest in Investing (“Appel a Manifestation d'Interet a Investir” in French) targeted at French private fixed operators.[2] Private operators had to declare the areas (excluding very dense areas) of France in which they intended to invest without public subsidies in the coming 5 years (Decision 2010-1312 of December 14 2010 https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000023443152).

The French authorities included in the so-called “AMII areas” all areas for which at least one private operator had responded to this call. French authorities considered that, in other areas not included in AMII areas, coverage by FTTH should be open to public intervention and public subsidies: these are referred to as “Public initiative networks” (“Reseaux d'initiative publics” (RIP)) areas.

This 2011 Call for Expressing Interest in Investing defined “AMII areas”, which cover 40% of the population in 3616 French municipalities outside very dense areas. Therefore, for FTTH regulatory purposes, France is essentially divided into 3 types of areas:

[2] See https://www.arcep.fr/fileadmin/reprise/communiques/amii.pdf.

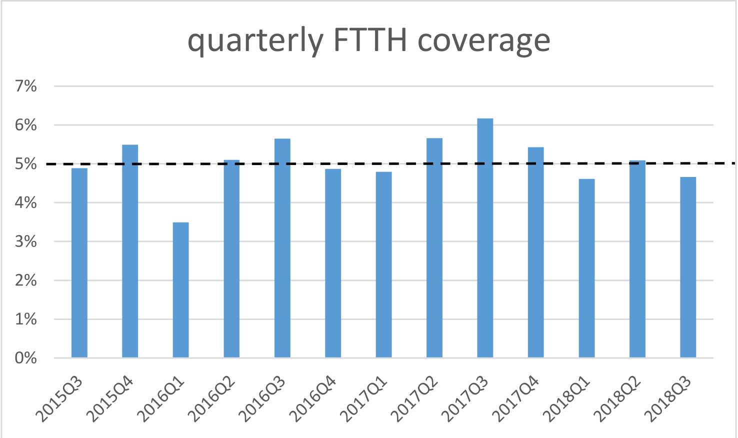

Fig. 1. Average FTTH quarterly coverage from 2015Q3 to 2018Q3: The quarterly FttH coverage measured here is newly covered housings as a share of total housings in the municipality. The percentage refers to housings and is not a growth rate.

– "ZTD", very dense areas covering 17% of the population where a specific regulation applies, favoring infrastructure competition between operators except inside buildings;
– "ZMD-AMII", less dense areas covered by private FTTH investment, subject to co-investment obligations, representing 40% of the population; and
– "ZMD-RIP", less dense areas where FTTH investment will be managed by local public authorities and receive public subsidies, representing 43% of the population. In these areas, both ZMD co-investment obligations and complementary access obligations apply.

The procedure described above, which has led to these coverage commitments, also has its equivalent in the EECC. This procedure is not in Article 76, which does not include any provision related to coverage obligations, but in Article 22 associated with Article 29. Under Article 22, public authorities may impose private operators to reveal the areas that they intend to cover. Under Article 29, public authorities may fine operators if their actual roll-outs diverge from the intentions of roll-outs that they have communicated under Article 22, thereby transforming coverage intentions into coverage obligations. Obviously, no formal link can be established between Articles 22 and 29 EECC and the respect of coverage obligation in France during our study period (2015–2018), because EECC will be applicable by the end of 2020, long after our study period. However the substance of the procedure described in Articles 22 and 29 EECC is similar to the procedure used in France, even if all of the details are not aligned. Therefore, our results for France concerning coverage achievements in relation to coverage commitments could be relevant to anticipate the effects of Articles 22 and 29 EECC.

The incentives of operators and notably of the incumbent operator Orange to respect the coverage commitments that they have made in the process are the following.

Initially, if operators did not fulfill their coverage commitments, they faced the risk of seeing the activity of rolling out and of operating fiber infrastructure being captured by local authorities investing in their own subsidized infrastructure. For an infrastructure-based operator such as Orange, such an outcome would be a critical threat to its long-term economic model. This risk existed both locally (a local authority could argue about the deficiency of private initiative and roll out its own network) and nationally (if operators' commitments could not be trusted, all the process organized by the government to define areas where private initiative should prevail would be questioned). Credibility in general is vital for an operator such as Orange in all its relations with local and national authorities beyond the issue of FTTH coverage, and Orange cannot afford not to be trusted.

Since then, French law has given to the National Regulatory Authority (ARCEP) the power to monitor the fulfillment of coverage obligations by private operators and to impose fines if commitments are not respected. It is the object of Article L 33-13 of the French Code of Telecom.[3]

For these reasons, the speed of FTTH roll-out in each municipality is driven by this regulatory obligation of full coverage within 5 years. This roll-out obligation corresponds to an average incremental roll-out of +5% coverage per quarter, which is the mean value of the figure returned by the descriptive statistics, as shown in Fig. 1.[4] Therefore, in the French dataset used for this study, FTTH roll-out speed in municipalities can be considered to be exogenous fixed by regulatory coverage obligations.

[3] A detailed description of this process of monitoring is available on ARCEP website on the following link: https://www.arcep.fr/la-regulation/grands-dossiers-reseaux-fixes/la-fibre/engagements-operateurs-zones-amii.html.

[4] A weighted average by the number of housings in the municipalities is used. The FTTH coverage achieved in the first quarter at the starting point is excluded from the calculation.

Orange and SFR were the only two operators to make a significant commitment to covering AMII areas. In practice, during our study period (2015–2018), an overwhelming proportion of the AMII areas were covered by Orange, because in the meantime, SFR was acquired by Numericable, the French cable operator, an event that changed the FTTH investment plans of SFR.

Our empirical study is limited to AMII areas covered by private investment and subject to the regulatory framework of ZMD areas. In the study areas, FTTH initial investment and FTTH co-investments are the only variables by which market structure can vary in space and time. No other market structure variation exists:

- First, nowhere does FTTH infrastructure competition occur in ZMD, since only one FTTH network is deployed.
- Second, renting FTTH access lines at premium prices is available everywhere FTTH exists.
- Finally, all market players provide copper-based fixed broadband access services in the areas included in our study and over the whole study period.

The ongoing investment and co-investment of market players in the single FTTH network across studied municipalities means that the number of FTTH investors varies both in time and in space. The only other variation between municipalities, besides FTTH investment and co-investment, is the presence or the absence of cable, but as already mentioned, cable in France has a small and stable market share and a fixed footprint.

4. The data

We combine several panel datasets of 3573 French ZMD AMII municipalities[5] over 13 quarters, from 2015 to 2018. For each municipality in each quarter, we obtain information about FTTH coverage, the entry of FTTH investors and the municipality's socio-demographic characteristics.[6] We have also collected the FTTH adoption for three quarters 2018Q1, 2018Q2, and 2018Q3 and Orange's fixed broadband market penetration (ADSL+FTTH), measured annually at the year end of 2015, 2016, and 2017.[7] We are able to merge these datasets using unique identifiers for each municipality.

4.1. FTTH entry and co-investment

For each quarter, ARCEP requests that all operators provide a list of information for each concentration point (PM), such as the reference of the PM that contains a municipality identifier, the number of FTTH connectable housings, the number of co-investors with the long-term rights to the FTTH network and the date of the PM adduction.[8]

The co-investment variable is built with two pieces of information: (1) the presence of co-investors benefiting from long-term rights at the PM level and (2) the date of the PM adduction by the commercial operator. Information (1) records the presence of co-investors for at least one PM in the study municipality. Information (2) allows for dating approximately (to the nearest quarter) the co-investing date for a PM (thus for a municipality). The co-investment is therefore populated for each new PM deployed in the quarter. The co-investment variable indicates the absence (0) or the presence (1) of one or more co-investors.

The information on co-investment, in addition to being provided to ARCEP the French regulator, can also be obtained from public sources, namely, the websites of operators. For instance, SFR publishes a map of France showing the municipalities in which FTTH is deployed. For each municipality, it is possible to observe when the co-investors deployed their network in co-investment (cf. Bourreau, Grzybowski et al. (2018) where such an approach has been used).

4.2. FTTH adoption

The fiber adoption rate is calculated, at the municipality level, by dividing the number of FTTH subscribers by the number of FTTH connectable housings. The number of FTTH connectable housings is obtained from an open database published by the French telecom regulator ARCEP. Fiber quarterly adoption data are only obtained for Orange ZMD-AMII municipalities, i.e., 2991 municipalities, or approximately 80% (more precisely 82.7%) of all ZMD-AMII municipalities. For each of 2991 municipalities, 3 observations, at respectively 2018Q1, 2018Q2 and 2018Q3, are collected from the data provided by Orange at the request of ARCEP, to establish ARCEP's regulatory adoption statistics. This selection of areas is unlikely to bias our results for the following reasons. First, 80% represents a large percentage of the total. The missing 20% would need to have greatly different average characteristics from those 80% to significantly bias the outcome. Second, such a large difference is unlikely because the AMII areas are already relatively homogeneous: they exclude both most dense areas covering 17% of the population, and less dense areas covering 43% of the population. No extreme variations are possible. Finally, such a large difference is also unlikely because the split between Orange and SFR areas has been welcomed by the French Regulatory Authority of Electronic Communications which would not have been the case had the deal been unfair.

[5] We obtained information about 3573 of the 3616 ZMD AMII French municipalities. Some of the socio-demographic variables are not available for the remaining 43 municipalities.

[6] To avoid simultaneity issues, we use one-year lagged values for socio-demographic characteristics.

[7] FTTH coverage in each municipality is the ratio of FTTH connectable housings to the number of housings in each municipality. However, FTTH adoption rate is defined as the ratio of the total number of FTTH customers to the number of FTTH connectable housings at municipality level.

[8] The adduction corresponds to the connection of the horizontal network (deployed in the street) to the vertical network deployed by the building operator https://fibre.guide/deployment/adduction.

4.3. Competition-related data

We consider that Orange's fixed broadband market penetration, calculated by dividing the number of retail broadband (ADSL + FTTH consumer access) owned by Orange by the number of housings in the municipality is representative of the level of competition in the local broadband consumer market. These data only include statistics on Orange's retail subscribers at year end of 2015, 2016 and 2017. They come from Orange retail information system.[9] According to ARCEP open data publications, the number of subscriptions to fixed broadband is slightly increasing over the study period. The fixed broadband subscriptions increased from 27 million in 2015 to 29 million in 2018. In case of a stable Orange penetration rate on the number of subscriptions, it turns out that the increase in total subscriptions is attributed to a slight increase in the penetration rate of Orange's competitors. Similarly, if Orange penetration rate decreases, it means that the increase of total number of subscriptions is due to a significant increase in the penetration rate of Orange's competitors. Moreover, the fact that the total number of subscriptions increases over the study period allows the eventual switch from broadband to mobile services to be considered negligible. Therefore, Orange retail penetration ratio is indeed a relevant indicator of competition intensity in the fixed broadband market.

4.4. Characteristics of municipalities

We obtained sociodemographic characteristics for 3514 of the 3616 ZMD-AMII French municipalities. Some of the sociodemographic variables are not available for the remaining municipalities. The socio-demographic characteristics of the municipalities are mostly obtained from the French national statistical office (INSEE) or the French telecom regulator (ARCEP). Specifically, we use a longitudinal database for the period of 2014–2017: median income, education level, number of housings, share of apartment housing, share of housings connectable to cable access and population density. The education level is measured by the percentage of the out-of-school population that is 15 years old or older with a bachelor's degree or higher. The share of housings eligible for cable access at the municipality level is provided by ARCEP. The cable coverage rate, without taking into account the speed upgrade, is quite stable over time. Indeed, the cable footprint has not changed since the 1990s, when the roll-out of the "plan cable" launched by French government in 1982 ended. The total number of deployed cable access increased only by 6% from 2013 to 2018, reflecting urbanistic and demographic evolution within the cable footprint. In addition, before the study period, the cable operator was bought out and became SFR in 2014, investing or co-investing exclusively in FTTH outside the cable footprint. There is therefore no cable strategy independent of the fiber strategy.

An additional municipality-level variable is collected and used as an exogenous variable to construct an entry model: the ADSL line attenuation (averaged at the municipality level), measured in decibels. It can be obtained from public sources such as Degrouptest.[10] This measure is a faithful proxy of the distance from a municipality to the Main Distribution Frame (MDF).[11] The distance computed from the Geographic Information System (GIS) is sometimes used as an instrumental variable in the literature on impact studies of Internet access (see for instance Falck et al. (2014)). Copper line attenuation is a more appropriate measure than the distance computed from the GIS since the ADSL line is not a straight line and often follows the roads and also because it considers the diameter of copper wires. Copper line attenuation accurately determines the eligibility of access to ADSL[12] and also the speed of the ADSL offer. In the rest of this paper, we refer to copper line attenuation as the distance from municipality to MDF, which is more commonly used in the literature.

4.5. Summary statistics

Table 1 displays some statistics on ZMD-AMII municipalities with or without FTTH entry.

Table 1 shows that a larger population, a greater density, a larger share of apartment housing are correlated with FTTH investor entry, and a greater distance to MDF is associated with single investment.

In Table 2, we present the summary statistics of our dependent variables: FTTH adoption is observed only for 80% of 3616 municipalities, i.e., ZMD AMII under Orange's responsibility.

As shown in Table 2 the FTTH adoption is higher in co-investment municipalities than single investments. Orange's fixed broadband market penetration, measured at year end, is lower in co-investment municipalities.

9 This data source is different from the adoption data source, resulting in a different observation period.

10 https://www.degrouptest.com/.

11 The MDF is a termination point within the local telephone exchange where exchange equipment and terminations of local loops are connected by jumper wires at the MDF.

12 The eligibility threshold for a DSL line corresponds to a maximum line attenuation of 78 dB, allowing for a nominal speed of up to 512 kilobits per second (kbps), or slightly more than 5 km for a copper line with a diameter of 0.4 mm.

Table 1
Summary statistics: municipality characteristics 2015–2018 in three groups of municipalities: no investor, only one investor and at least two investors[a].

	No investor	1 investor	⩾ 2 investors	All
Nb of housings per municipality	1597	5249	11 471	3500
Distance to MDF (km)[b]	2.41	2.65	2.33	2.41
Share of apartments	15%	36%	47%	22%
Income (Euros per year)	22 246	22 995	21 509	22 162
Population density (per km^2)	382	1452	1788	684
Education[c]	46%	50%	47%	46%
Cable	9%	22%	30%	13%
Number of obs[d]	8133	599	1810	10 542

[a]The numbers in the table are mean values at the end of the period.

[b]The distance to MDF is measured by the loss of electrical signal, then converted to km.

[c]The level of education is measured by the percentage of the out-of-school population that is 15 years old or older with a bachelor's degree or higher.

[d]One observation is recorded for each municipality each quarter.

Table 2
Summary statistics: FTTH adoption and competition by market structure: all observations reported below as a share of the municipality's total housings.

FTTH adoption (at quarter end of 2018Q1 2018Q2 2018Q3)	No. obs	mean	std dev
No FTTH entry (0 FTTH investor)	5543	0	0
Single-investment (= 1 investor)	526	16.9%	0.175
Co-investment (⩾ 2 investors)	2733	23.3%	0.242
Orange's fixed broadband market penetration (FTTH + ADSL) at year end of 2015 2016 2017			
No FTTH entry (0 FTTH investor)	8133	45%	0.15
Single-investment (= 1 investor)	599	38%	0.17
Co-investment (⩾ 2 investors)	1810	33%	0.12

5. Econometric model

This paper primarily aims to examine the extent to which the growth in FTTH adoption is causally affected by co-investment, that is, by the entry of co-investors in addition to Orange which is the initial investor in the studied areas. To estimate the effect of co-investment on FTTH adoption, we borrowed the model used by Manuszak and Moul (2008) and specified the following reduced form econometric model:

$$adoption_{it} = \lambda X_{it} + g(N_{it};\gamma) + u_{it} \tag{1}$$

where $adoption_{it}$ is the FTTH adoption in quarter t in municipality i, and X_{it} is a vector of municipality-level socio-demographic characteristics, including the median income, the education level, the share of housings eligible for cable access and population density. The function $g(N_{it};\gamma)$ captures the effect of the number of investors with N_{it} characterizing the market structure and γ reflecting the incremental effects of additional investors. u_{it} reflects unobserved factors that impact adoption.

In this simple regression however, we face the crucial issue of a potential correlation between N_{it} and u_{it}. Indeed, contrary to one of the necessary conditions for correct inference, market structures are not randomly assigned. Instead, FTTH providers base their entry decision on demand and cost factors as well as the anticipated entry of their competitors. All telecommunication providers have greater incentives to invest in municipalities where full coverage is the easiest and least expensive. The unobserved coverage cost therefore impacts both adoption and market structure, which may yield inconsistent estimation of the relationship between these two variables by inconsistent estimates of γ and λ. We could have resolved this issue using an instrumental variable, but a good instrument remains difficult to find in this case. Thus we use an alternative model that describes the observed FTTH investment entry. We use this latter model to generate correction terms for the regression of the FTTH coverage to account for potential correlations between the error term and N_{it}.

Following Bresnahan and Reiss (1991), we introduce a latent profit function as

$$\Pi_{it}(Z_{it}, N_{it}, e_{it};\theta) = \pi_{it}(Z_{it}, N_{it};\theta) + e_{it} \tag{2}$$

where Z_t is a vector of municipality-level characteristics that impact profitability in a municipality at time t, e_t are unobserved factors, and θ are unknown parameters of profit function Π_t. According to Manuszak and Moul (2008), the latent profit function Π_t should be interpreted as the reduced form of the expected present discounted value of profits resulting from competition between firms, once all of them have entered in the market. We assume that profits are decreasing in N_{it}. In a Nash equilibrium, investors enter the FTTH deployment until no additional investors would be profitable. The market structure is characterized by the following restrictions on latent profits:

$$N_{it} = 0 \Leftrightarrow \pi_{it}(Z_{it}, N_{it} = \mathbf{1}; \theta) + e_{it} < 0$$
$$N_{it} = 1 \Leftrightarrow \pi_{it}(Z_{it}, N_{it} = \mathbf{1}; \theta) + e_{it} > 0, \pi_{it}(Z_{it}, N_{it} = \mathbf{2}; \theta) + e_{it} < 0$$
$$N_{it} = 2 \Leftrightarrow \pi_{it}(Z_{it}, N_{it} = \mathbf{2}; \theta) + e_{it} > 0$$

Following Bresnahan and Reiss (1991), we can estimate the parameter θ by maximum likelihood. Moreover, we impose distributional restrictions on the two error terms, by assuming that, conditional on X_{it} and Z_{it}

$$\begin{pmatrix} u_{it} \\ e_{it} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_u^2 & \sigma_{ue} \\ \sigma_{ue} & 1 \end{pmatrix} \right) \tag{3}$$

From the distribution assumptions, it follows that

$$E[adoption_{it}|X_{it}, Z_{it}, N_{it}] = \lambda X_{it} + g(N_{it}; \gamma) + \sigma_{ue} h(N_{it}, Z_{it}; \theta) \tag{4}$$

where

$$h(N, Z_{it}; \theta) = \begin{cases} \frac{\phi[\pi(N, Z_{it};\theta)] - \phi[\pi(N+1, Z_{it};\theta)]}{\Phi[\pi(N, Z_{it};\theta)] - \Phi[\pi(N+1, Z_{it};\theta)]} & \text{for } 0 < N < N^{max} \\ \frac{\phi[\pi(N^{max}, Z_{it};\theta)]}{\Phi[\pi(N^{max}, Z_{it};\theta)]} & \text{for } N = N^{max} \end{cases} \tag{5}$$

with $\phi(.)$ and $\Phi(.)$ representing the pdf and cdf of the standard normal distribution,respectively. The term $\sigma_{ue} h(N_{it}, Z_{it}; \theta)$ reflects the potential correlation between u_{it} and N_{it} by including the possibility that $E[u_{it}|N_{it}]$ is not equal to zero.

It is then possible to decompose the error term u_{it} in the adoption equation into a sum of two terms: $\sigma_{ue} h(N_{it}, Z_{it}; \theta)$ and ε_{it}, where ε_{it} is of zero mean conditional on N_{it} and Z_{it} by construction. The model is an ordered probit in which the outcome variable describes the number of investors present in a municipality with the latent profit function

$$\Pi_{it}(Z_{it}, N_{inv}, e_{it}; \theta) = \beta\ Z_{it} - \Delta_1 * I_{it}(N_{inv} \geqslant 1) - \Delta_2 * I_{it}(N_{inv} \geqslant 2) + \nu_t + e_{it} \tag{6}$$

Δ_1 measures the impact of the entry of a monopoly. Δ_2 presents the incremental impact of adding one or more co-investors. I(.) is an indicator equal to one if the expression in parentheses is true. Time fixed effects are controlled by the quarter indicators (ν_t).

The functional form for FTTH adoption can be expressed as:

$$adoption_{it} = \lambda X_{it} - \gamma_1 I_{it}(N_{inv} \geqslant 1) - \gamma_2 I_{it}(N_{inv} \geqslant 2) + \sigma_{ue} h(N_{inv}, Z_{it}; \hat{\theta}) + \varepsilon_{it} \tag{7}$$

where γ_1 measures the impact of single investment on adoption. γ_2 measures the additional impact of co-investment entry. $h(N_{inv}, Z_i; \hat{\theta})$ is the correction term computed using the first stage maximum likelihood estimates of $\theta = \{\beta, \Delta_1, \Delta_2\}$.

We introduce region fixed effects into Eq. (7) to account for time-invariant factors. We use three exogenous variables used only in the first stage. The first exogenous variable is the number of housings which measures the market size. The second exogenous variable is the share of apartment housing, which is a proxy for deployment cost. The third exogenous variable is the distance to MDF, which represents the quality of ADSL speed.

6. Estimation results

This section presents the results from the model and data described above. We provide the estimates from the first stage entry model, followed by the FTTH adoption and competition regressions with OLS and a two-stage control-function approach.

6.1. First stage : entry model, FTTH investment entry determinants

We rely on the variables described in the data section above to understand the determinants that affect investors' entry decisions (see Table 3).

At this first-stage (FS), the dependent variable "Number of investors" takes the value 0/1/2 (0 = no investors; 1 = 1 single investor; 2 = at least 1 co-investor). These three modalities of market entry are considered endogenous. The results from the first-stage entry model, i.e. the determinants of the investment decision, correspond to the three columns of the table. Three main exogenous variables enter in the entry model: number of housings, share of apartment housing, and distance to MDF. The first-stage entry estimates, while interesting on their own, are used primarily as a tool to correct potential endogeneity in the second-stage regressions. To be able to assume that the exogenous variables of the first-stage impact the entry decision but do not impact the dependent variables of the second-stage (exclusion restrictions), we compute two different first-stage equations, each corresponding to one of the future dependent variables of the second-stage. Indeed, these future dependent variables (adoption and competition) of the second-stage may be differently impacted by the exogenous variables of the first-stage. Considering this restriction, for each of the two equations, we retained among the factors of decision only those with no direct impact on the future corresponding dependent variable, except through the incentive for investors to enter the market (first-stage). For the first future dependent variable "adoption", we use "number of housings" and "share of apartment housing" but as a long distance to MDF and therefore a poor ADSL speed could favor the decision to adopt FTTH, we exclude here the variable "distance to MDF". For the second dependent

Table 3
Parameter estimates from entry model : The dependent variable “Number of investors” takes the value of 0/1/2. The value 0 corresponds to no investor, the value 1 to only one investor, and the value 2 to at least 2 investors.

Variables	FS adoption Nb of investors	FS competition Nb of investors
Share_apartment	2.498***	3.389***
	(0.155)	(0.223)
nbhouse	0.030***	0.069***
	(0.005)	(0.011)
DistanceToMDF		0.021***
		(0.002)
Income	0.039***	0.100***
	(0.011)	(0.016)
Density	−0.014	−0.022
	(0.021)	(0.031)
Education	−0.520	−2.032***
	(0.392)	(0.526)
Cable	0.324***	0.403***
	(0.065)	(0.102)
Fixed effect firm 1 Δ_1	1.846***	3.816***
	(0.167)	(0.374)
Fixed effect firm 2 Δ_2	3.216***	4.177***
	(0.175)	(0.375)
Quarter fixed effect	Y	Y
Region fixed effect	Y	Y
Observations	8802	10 542

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1.

variable, “Orange broadband market penetration”, we use the three instruments together. We consider that these 3 instruments can hardly have a direct impact on “Orange broadband market penetration”, except via co-investment.

In the two regressions, the three exogenous variables (number of housings, share of apartment housing, and distance to MDF) correspond to demand and cost factors. First, the profitability of a market increases with market size, which is captured by number of housings. To capture the cost of deployment, we use the share of apartment housing. Finally, longer distance to MDF leads to a deterioration in the quality of ADSL, and hence to increased demand for FTTH. As anticipated, the estimates for number of housings, share of apartment housing, and distance to MDF are all positive.

The control variables have the expected sign. The positive coefficient for the median income suggests that profitability is greater in more affluent municipalities. The coefficient for population density level is not significant. Finally, the positive and significant coefficient for the variable “cable” indicates that the entry of FTTH investment is stimulated by the presence of cable infrastructure. The estimate of the single investment effect, Δ_1, suggests that investing in FTTH triggers the migration from ADSL to FTTH and reduces a single investor’s broadband profits, due to FTTH deployment costs. The estimate of the co-investment effect, Δ_2, indicates that the entry of co-investors in the municipality is an important determinant of profitability because entry by additional investors reduces each firm’s profits significantly.

In the following subsection, we first consider the investment entry exogenous and then endogenous using OLS and then two-stage control-function regression.

6.2. Positive impact of co-investment on FTTH adoption in Orange ZMD-AMII municipalities

Under the assumption that the co-investment variable is exogenous, we first conduct an OLS regression. It is important to note that the endogenous variable is noted differently in the two stages. In the first stage, the endogenous variable was the number of investors in FTTH with NbInvestors taking 3 different values as mentioned above (0 = no investors; 1 = 1 single investor; 2 = at least 1 co-investor). In the second stage, to be able to explicitly demonstrate the co-investment effect, we borrowed Manuszak and Moul (2008)’s specification, reformulating the variable NbInvestors into 2 dummies which are “FTTHEntry” (at least one investor, NbInvestors $\geq$ 1) and “co-investment” (NbInvestors $\geq$ 2). The second dummy allows for isolating the pure incremental effect of co-investment. Our data include the FTTH quarterly adoption and the investment entry (0/1/2+ investors) for each municipality. We control for the municipality level socio-demographic variables. The region fixed effect and the time fixed effect are introduced.

We present the results from regression without correction for the endogeneity of investor entry in the left panel of Table 4, and for the comparison report of the estimates using correction terms generated from the first-stage in the right panel. In the left panel in Table 4, the pooled OLS estimator suggests a positive correlation between FTTH entry (number of investors $\geq$ 1) and FTTH adoption, and also between the co-investment entry (number of investors $\geq$ 2) and FTTH adoption. More specifically, the FTTH adoption rate is 16.7% of FTTH home passed on average in areas with at least one investor. The adoption is improved for co-investment entry, i.e. at least two investors, by an additional adoption of 7.3% of FTTH home passed. In other words, the FTTH adoption rate is about 16.7% in municipalities with only one investor, 24% (16.7% + 7.3%) of FTTH home passed in municipalities with at least

Table 4
FTTH adoption regression.

Variables	Uncorrected adoption	Corrected adoption
FTTHEntry	0.168***	0.122***
	(0.008)	(0.013)
Co-investment	0.073***	0.079***
	(0.008)	(0.009)
Income	0.004***	0.003***
	(0.001)	(0.001)
Density	−0.011***	−0.005**
	(0.003)	(0.002)
Education	−0.045	−0.022
	(0.031)	(0.025)
Cable	−0.017**	−0.007
	(0.007)	(0.006)
Hazard		0.026***
		(0.006)
Quarter fixed effect	Y	Y
Region fixed effect	Y	Y
Constant	−0.062***	−0.055***
	(0.015)	(0.012)
Observations	8,802	8,802
R-squared	0.387	0.391

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1.

two investors. However, as mentioned above, the number of investors (FTTH entry, co-investment entry) is not randomly assigned among municipalities but rather consists in strategic decisions made by investors that evaluate FTTH demand and deployment cost.

Therefore, we use a two-stage control-function estimation to address the endogeneity of the FTTH investment decision. Using an entry model in the first stage, we estimate an equilibrium model of entry that predicts the number of investors in a municipality. The control function estimates, reported in the right panel of Table 4, show that the FTTH adoption rate is 12.3% of FTTH home passed in areas with only one investor, 20.2% of FTTH home passed (12.3% + 7.9%) in municipalities with at least two investors. Unobserved FTTH demand and deployment cost shocks in a municipality might influence not only FTTH adoption but also the number of investors. For example, municipalities with unobserved high costs are likely to be failing to attract a large number of investors, or even only one investor. Similarly, unobserved positive demand shocks may result in higher adoption and an unusual number of investors in a municipality, in which case the impact of the FTTH entry on adoption might be overestimated.

Both OLS and two-stage with entry model, suggest that co-investment leads to greater FTTH adoption. This result is intuitive since Orange's ADSL customers and co-investors' ADSL customers migrate respectively to Orange's FTTH offer and co-investors' FTTH offer[13] without switching providers. The addition of both migrations favors a more efficient FTTH adoption. The adoption of FTTH might depend on several factors. First, a consumer can adopt FTTH if and only if his or her house is already connected to the FTTH network (FTTH home passed). Second, since most consumers already have ADSL access, the migration from ADSL to FTTH might be motivated or slowed down not only by the willingness to pay for FTTH, but also by the switching cost of technological changes or the switching cost of Internet provider change. In the case of co-investment, we expect the switching cost of Internet provider changes to be reduced if an ADSL subscriber migrates to an FTTH offer within the same provider. However, in the case of single investment by Orange, competitors' ADSL consumers would face a double switching cost, related to changes in technology and providers, and might therefore be more reluctant to switch from ADSL to FTTH.

6.3. More intense competition in the broadband market with co-investment

In this section, we explore how broadband market competition is affected by co-investment. The broadband market in France consists mainly of ADSL and FTTH offers, since cable has a small and stable share of the market. During the period of our study, the number of ADSL customers was far greater than the number of FTTH customers. The ADSL market is competitive with tariffs which are among the lowest in Europe. Since ADSL and FTTH are substitutes, consumers are gradually migrating from ADSL to FTTH. The objective of the regulation is to guarantee a satisfactory level of competition during and after the transition from ADSL to FTTH. For this purpose, we measure at the end of each year the broadband market competition by the broadband market penetration held by Orange, that is, the ratio of Orange's retail ADSL and FTTH customers to the number of housings.[14] As mentioned in the data

[13] The three FTTH co-investors are also LLU (Local Loup Unbundling) operators, i.e. Orange's ADSL competitors.

[14] We collected the number of housings in each municipality from INSEE for the period 2009–2016. For 2017 and 2018, data are not available. We perform a regression of the number of housings over the variable year for each municipality from 2009 to 2016, in order to predict the number of housings for 2017 and 2018. Thus we reconstruct the number of housings for the period 2009–2018 to calculate Orange total retail broadband market penetration.

Table 5
Competition regression (Orange's fixed broadband market).

Variables	Uncorrected MPBBOrange	Corrected MPBBOrange
FTTHEntry	0.002	−0.011*
	(0.006)	(0.006)
Co-investment	−0.033***	−0.059***
	(0.006)	(0.008)
Income	0.005***	0.004***
	(0.001)	(0.001)
Density	−0.031***	−0.027***
	(0.003)	(0.003)
Education	0.266***	0.286***
	(0.041)	(0.041)
Cable	−0.128***	−0.121***
	(0.007)	(0.007)
Hazard		0.025***
		(0.005)
Quarter fixed effect	Y	Y
Region fixed effect	Y	Y
Constant	0.231***	0.246***
	(0.018)	(0.018)
Observations	10,542	10,542
R-squared	0.510	0.512

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1.

section, there is no decrease in total fixed broadband subscription. As a result, a stable Orange penetration rate indicates at least stability of the competitors' penetration rate, and a decrease in the Orange penetration rate indicates at least symmetrical growth in the penetration rate of Orange's competitors. The variable "co-investment" corresponds to the presence of co-investment for at least one PM in the year. We run the regressions following Eq. (7) by replacing "adoption" with "MPBBOrange" (Orange's fixed broadband market penetration), without and with the correction term generated by the first-stage entry model regression. These regressions include the same set of explanatory variables as those in Table 4.

Without the correction term, the insignificant coefficient of "FTTH entry" shows that Orange would not gain in broadband market penetration in municipalities with Orange investment alone. In municipalities with co-investment, Orange's fixed broadband market penetration loses 3.3%. With the correction term, our results show that Orange's total broadband market penetration is very weakly impacted in the municipalities where Orange invests alone but decreases by 5.9% in the municipalities with co-investment.

In the municipalities where Orange invests alone, Orange's consumers are migrating from ADSL to FTTH, without impacting the total number of its broadband customers. As a result, Orange's fixed broadband market penetration is not affected by this type of investment. Instead, in municipalities with co-investment, if the migration from Orange's ADSL to competitors' FTTH dominates the migration from competitors' ADSL to Orange's FTTH, Orange's fixed broadband market penetration might decrease, which is what we found in Table 5, both with uncorrected and corrected regressions.

7. Conclusions

The demand for faster and better-quality broadband access is a key driver of FTTH adoption and fixed broadband competition, and therefore of co-investment. The aim of this paper is to assess the effects on FTTH adoption and broadband competition of FTTH co-investment offers as introduced by the regulatory framework of FTTH in French ZMD areas in 2011 and encouraged in the new EECC. We address this issue by providing empirical evidence for the positive impact of co-investment on FTTH adoption and broadband market competition. We utilized several French municipality-level datasets that provide data for the period of 2015–2018. During this period, co-investment in FTTH deployment was introduced in less dense municipalities (ZMD and AMII) and rapidly developed.

We built an original dataset that include the quarterly investors entry, FTTH adoption and Orange's fixed broadband market penetration. First, we find significant determinants of investor entry related to FTTH demand and cost factors. Second, introducing a two-stage control-function approach to overcome the endogeneity of investor entry, we find that co-investment offers increase FTTH adoption and enhance competition in the retail broadband market. Therefore, the new European Electronic Communications Code appears to be justified in encouraging co-investment as an alternative to classical access obligations for FTTH.

The analysis presented in this paper has some limitations that could be addressed in future work. In particular, our results only reflect the particular regulatory and commercial situation of the fixed broadband market in France during the study period.

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