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Estimating the impact of co-investment on fiber to the home coverage, adoption and competition*

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Abstract

Does co-investment enhance fiber to the home (FTTH) coverage, adoption and competition? We combine several French municipality-level datasets and use a two-stage control-function approach to answer this question. In the first stage, we estimate an equilibrium model of entry that predicts the number of FTTH investors in a municipality. In the second stage, we insert the correction term derived from the entry model in the FTTH coverage (adoption, competition) regression to correct for endogeneity of investor entry. The two stages make two contributions. First, we find some FTTH demand and cost factors, which are significant determinants of investor entry. Second, we show that the presence of co-investors does not impact coverage dynamics at the municipality-level, which appears to be determined by French regulatory coverage obligations, i.e., full coverage in five years. In addition, we observe that the presence of co-investment, leads to an increase of 7.6% in FTTH adoption during the 2015-2018 study period and also a more intense competition as shown through the decrease in Orange total retail broadband market penetration by 7.8% for Orange, which is the incumbent operator in France. Our findings confirm that co-investment supports the policy objectives of adoption and competition and should be supported by regulation.

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JEL Classification: L43, L51, L96

1 Introduction

Should telecommunications operators be encouraged to co-invest in Very High Connectivity Networks (VHCN), as defined in the new European Electronic Communications Code¹ ? This article contributes to answering this question by providing detailed empirical estimations of the influence of co-investment on Fiber to the Home (FTTH) coverage, 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 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 in order to compete with incumbents on copper-based broadband access services.

However, this access obligation, initially intended to open up access for competitors to copper infrastructure, has been extended to new investments in fiber access networks. But this access obligation has discouraged investments in assets replacing 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

¹Article 2(2)“(2) ‘very high capacity network’ means either an electronic communications network which consists wholly of optical fibre 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;”

could not indefinitely support the growing demand for faster connections. In addition, statistics revealed that Europe was below 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 take place, as 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, 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 like trying to square the circle. If the access price is high, FTTH retail prices will be high because, otherwise, there would be an illegal margin squeeze resulting from the relative positions of retail and access prices, and FTTH services will fail to attract customers using cheap copper-based broadband services. If the access price is low, non-investors are better off than investors because they benefit from the investment without being subject to its risk or even its costs. In either of these cases, potential investors have no benefit to expect from their investment and therefore no incentive to invest.
- The second extreme option would be the absence of an access obligation. The issue would not be challenging if infrastructure competition could exist in each part of the fiber network. However, and 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. Those 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, 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 into developing commercial arrangements among themselves. In France, detailed co-investment schemes have been 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 incumbent operators providing their competitors with appropriate forms of co-investment in their newly deployed fiber infrastructure may be exempted from other forms of access obligations. Before its adoption, Article 76 was hotly 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 coverage, more adoption and preserved or enhanced competition. We address this issue by providing empirical evidence on the quantitative causal impact of co-investment on the actual roll-out and adoption of FTTH networks in France as well as on the level of competition.

We use a dataset from 2015 to 2018 in the French municipalities belonging to the so-called “ZM”

or “Zones Moins Denses” (translated in English as less dense areas), a part of French territory where the French National Regulatory Authority 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 coverage, adoption and competition, because they are the model of the co-investment offers that may lead to an absence of further access obligations under Article 76 of the EECC.

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. It studies the relationship at the municipality level between co-investment, FTTH coverage within the municipality, adoption of FTTH service and total penetration of Orange access services in the municipality.

By using a two-stages entry model, as developed by Manuszak & Moul (2008), we are able to identify the influence of co-investment occurrence on those variables in these municipalities. We find that during the study period, co-investment has no significant causal effect on FTTH coverage within each municipality where FTTH entry has taken place: the speed of FTTH coverage within such municipalities appears to be driven by the regulatory obligations of full coverage within 5 years. However, our results indicate that co-investment where it takes place enhances FTTH adoption (7% more) and competition (7.8% less total penetration of Orange’s ADSL+FTTH access services).

The remainder of this article 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 on FTTH coverage and robustness checks. Section 7 presents additional results on the estimation of the impact of co-investment on FTTH adoption and competition. Section 8 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 literature on upstream cooperation between downstream competitors mostly includes theoretical papers. The article most closely related to our work is “Cooperative Investment, Access, and Uncertainty” by Bourreau *et al.* (2018a), 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 “Cooperation Between Firms for Infrastructure” 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 & Jacquemin (1988) “Cooperative and Non Cooperative RD in Duopoly with Spillovers”, as well as papers relating more specifically to the telecommunications industry: “Investment Sharing in Broadband Networks” Cambini & Silvestri (2013) and “Investment under Uncertainty and Regulation of New Access Networks” by Inderst & 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: “Technology Investment and Alternative Regulatory Regimes with Demand Uncertainty” by Cambini & Silvestri (2012), “Role of Access Charges in the Migration from Copper to FTTH” by Jeanjean & Liang (2012) and “Speeding Up the Internet: Regulation and investment in the European fiber optic infrastructure” by Briglauer *et al.* (2018). A good review of numerous studies can be found in “The Endgame of Telecommunications Policy: A Survey” by Vogelsang (2013), particularly, paragraph 2.2.2.4. “Empirical estimates of regulatory effects on investment”. The recent working paper “Unbundling the Incumbent and Entry into Fiber: Evidence from France” by Bourreau *et al.* (2017) 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 literature includes papers that have introduced 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 exclusionary constraint. Recent work, notably Manuszak & Moul (2008), Xiao & Orazem (2011), Nardotto *et al.* (2015), Molnar & Savage (2017) and Rosston *et al.* (2018) 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-step price equation. Our paper adds a new application of this methodology.

3 Regulatory framework of FTTH in the ZMD areas under study 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 “AMII” (“Appel a Manifestation d’Interet a Investir”) zone. 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 which

proportion of France 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 those that inspired the provisions supporting co-investment in 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 Mutualisation” (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 is obligated to inform other operators and allow them to share ab initio the cost 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 they take.

Operators wishing to co-invest in such a 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 enough customers to utilize such a capacity.

Co-investing by purchasing larger allotments is cheaper 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/tx_gspublication/RecoARCEP_mutualisation_fibre_01.pdf

These FTTH co-investment pricing principles which in less dense areas in France are consistent with the conditions imposed in article 76 and in Annex IV of the EECC to co-investment offers in order to avoid further access obligations. This 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 what proportion of France 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 operators². Private operators had to declare in which areas (excluding very dense areas) in France 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>).

²see <https://www.arcep.fr/fileadmin/reprise/communiqués/amii.pdf>

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 consider 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 réseaux d’initiative public (RIP) areas (in English, public initiative networks).

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:

- “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
- “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 those areas, both ZMD co-investment obligations and complementary access obligations apply.

Orange and SFR were the only two operators to make a significant commitment to cover AMII areas. In practice, during the period studied in our article (2015-2018), an overwhelming proportion of the AMII areas have been 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.

4 The data

We combine several panel data sets of 3573 French ZMD AMII municipalities³ over 13 quarters, from 2015Q2 to 2018Q3. For each municipality in each quarter, we obtain information on FTTH

³We obtained information on 3573 of the 3616 ZMD AMII French municipalities. Some of the socio-demographic variables are not available for the remaining 43 municipalities.

coverage, the entry of FTTH investors and the municipality’s socio-demographic characteristics⁴. We have also collected the FTTH adoption for three quarters 2018Q1, 2018Q2, 2018Q3 and Orange’s broadband market penetration (ADSL+FTTH), measured annually at year end of 2015, 2016, 2017. We are able to merge these datasets by using unique identifiers for each municipality.

4.1 FTTH coverage

FTTH coverage is obtained from an open database published by the French telecom regulator ARCEP. In this database, the FTTH coverage rate is defined as the share of households connectable to FTTH access in the municipality. To measure compliance with regulatory coverage requirements, every quarter ARCEP aggregates the information provided by all French operators. In fact, we use FTTH coverage progression between two consecutive quarters, knowing that ARCEP is imposing a full deployment in five years from the start of the deployment. This quarterly increase in coverage is directly associated with the new concentration points (PMs) deployed between two consecutive quarters.

4.2 FTTH entry and co-investment

For each quarter, ARCEP requests all operators to 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 households, the number of co-investors with the long-term rights to the FTTH network and the date of the PM adduction⁵.

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. The information (2) allows to date approximately (to the nearest quarter) the co-investing date for a PM (thus for a municipality). The co-investment is

⁴to avoid simultaneity issues, we use lagged values for socio-demographic characteristics before 2015, i.e., from 2009 to 2012.

⁵The 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>.

therefore populated for each new PM deployed in the quarter. Orange has co-invested in all AMII municipalities where SFR rolls-out FTTH as soon as the coverage of these municipalities has started. Only the presence (0/1) of co-investors is used, not the precise number of co-investors.

The information we use on co-investment can also be obtained from public sources, namely, the websites of co-investors. 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 have deployed their network in co-investment (cf. Bourreau *et al.* (2018b) where such an approach has been used).

4.3 FTTH adoption data

Fiber adoption data are collected from the data provided by Orange at the request of ARCEP, to establish ARCEP's regulatory adoption statistics. The fiber adoption rate is calculated by dividing the number of accesses to the fiber released by the number of connectable households of the PM and eligible for offers of the commercial operator. However, this rate of adoption is available in the data transferred by Orange to ARCEP for the AMII areas where Orange rolls-out FTTH. Unlike coverage, the adoption is measured with all connectable FTTH households and not only on new PMs deployed in the quarter since a household could subscribe to an FTTH offer on FTTH accesses deployed in previous quarters.

4.4 Competition-related data

Orange's broadband market penetration, calculated by dividing the number of retail broadband (ADSL + FTTH access) owned by Orange by the number of households in the municipality is representative of the level of competition in the local broadband market. These data only include statistics on Orange retail subscribers. They come from Orange retail information system.

4.5 Characteristics of municipalities

Some information on 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 2009-2012: average income, education level, number of households, share of apartment housing, share of households 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 or older with a bachelor's degree or higher. The share of households 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. The number of XDSL lines subscribed by the firms is obtained from Orange.

Additional municipality-level variables are collected from Orange and used as control variables or exogenous variables to construct an entry model. For instance the number of XDSL lines subscribed by the firms (directly sold by Orange and not via wholesale) and ADSL line attenuation (averaged at the municipality level), measured in decibels. This measure is a faithful proxy of the distance from a municipality to the Main Distribution Frame (MDF)⁶. Interestingly, 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. Copper line attenuation accurately determines the eligibility of access to ADSL⁷ 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.

4.6 Summary statistics

Table 1 displays some statistics on ZMD municipalities with or without FTTH coverage.

⁶The 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.

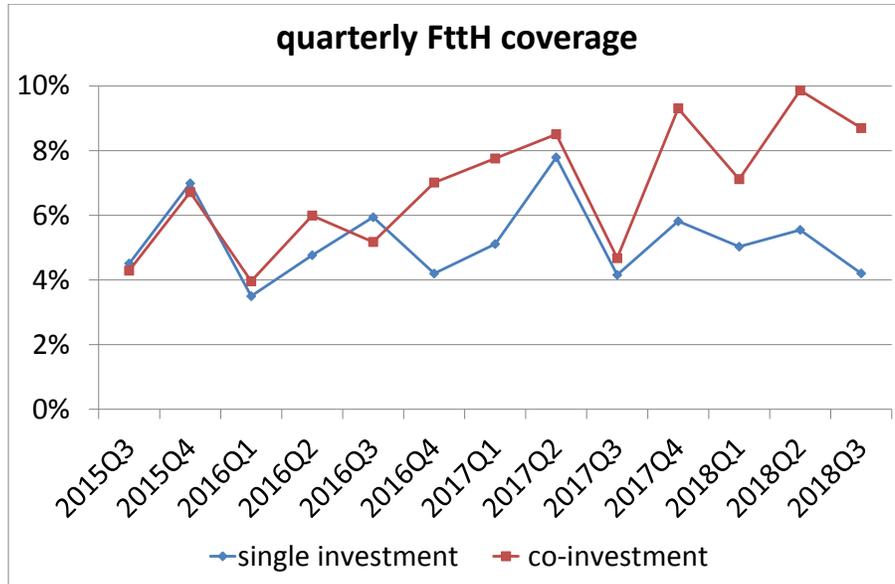
⁷The eligibility threshold for a DSL line corresponds to a maximum line attenuation of 78 dB, allowing a nominal speed up to 512 Kilobits per second (Kbps), or slightly more than 5 km for a copper line with a diameter of 0.4 mm.

Table 1: Summary statistics: municipality characteristics by market structure

	No investor	1 investor	≥ 2 investors	All
nbhouse	1641	7494	12347	3484
distanceToMDF	36.088	37.874	33.983	36.151
share_apartment	0.143	0.378	0.447	0.205
XDSL_business	0.010	0.017	0.018	0.012
income	0.027	0.029	0.026	0.027
density	0.203	0.834	0.955	0.364
education	0.669	0.738	0.698	0.682
cable	0.099	0.296	0.246	0.140
Number of obs	34819	6622	4245	45686

Table 1 shows that higher population, higher density, higher share of apartment housing and higher distance to MDF are associated with FTTH investor entry.

Figure 1: Average FTTH quarterly coverage from 2015Q3 to 2018Q3 by market structure



In Figure 1, we display the average quarterly FTTH coverage over time, around 5%, which is consistent with the obligation of full coverage in five years, i.e., 20 quarters (20 quarters

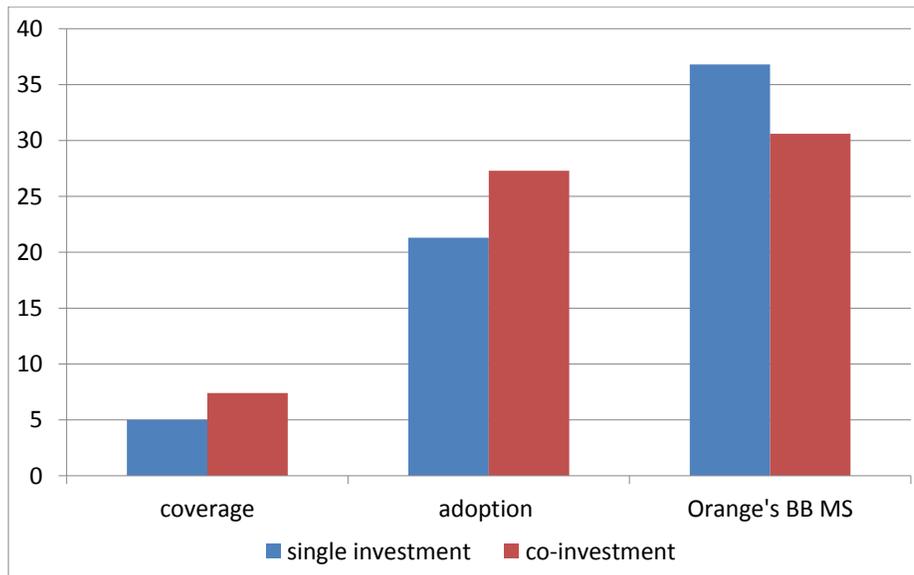
* 5%=100%). We can also observe that the average coverage tends to be higher with co-investment than with single-investment. In our data, there is wide dispersion in coverage, adoption and Orange’s broadband market penetration within market structure, suggesting the need for additional control variables.

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

Table 2: Summary statistics: FTTH coverage, adoption and competition by market structure

FTTH quarterly coverage (2015Q3-2018Q3)	Number	mean	std dev
No FTTH entry (0 FTTH investor)	34635	0	0
Single-investment (= 1 investor)	6735	0.050	0.088
Co-investment (≥ 2 investors)	4316	0.074	0.110
FTTH adoption (2018Q1-2018Q3)			
No FTTH entry (0 FTTH investor)	6092	0	0
Single-investment (= 1 investor)	418	0.213	0.170
Co-investment (≥ 2 investors)	2373	0.273	0.239
Orange’s broadband market penetration (FTTH+ADSL) (The largest FTTH investor) at year end of 2015 2016 2017			
No FTTH entry (0 FTTH investor)	8382	0.405	0.127
Single-investment (= 1 investor)	603	0.368	0.162
Co-investment (≥ 2 investors)	1832	0.306	0.119

Figure 2: comparison by market structure : FTTH quarterly coverage, FTTH adoption and Orange’s broadband market share



As shown in Table 2 and graphically in Figure 2, the FTTH quarterly coverage, the FTTH adoption is higher in co-investment municipalities than single investments. However, Orange’s broadband market penetration, measured at year end, is lower in co-investment municipalities.

5 Econometric model

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

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

where $dcovFTTH_{it}$ is the variation in FTTH coverage between two consecutive quarters t and $t - 1$ in municipality i , X_{it} a vector of municipality-level socio-demographic characteristics, including the average income, the education level, the share of households eligible for cable access and population density. N_{it} characterizes the market structure and u_{it} reflects unobserved factors that impact coverage. Each variable is defined at time t for the municipality i .

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 and coverage behavior of their competitors. Telecommunication providers may have an incentive to invest in municipalities where the work needed to cover it with FTTH is easy and then to all invest in the same municipality. The unobserved coverage cost therefore impacts both coverage and market structure which may yield inconsistent estimation of the relationship between those two variables by inconsistent estimates of γ and λ . We could have solved this issue by using an instrumental variable, but a good instrument remains difficult to find in this case. Then we use an alternative model that describes observed FTTH investment entry. We use this latter to generate correction term for the regression of the FTTH coverage to account for potential correlation between the error term and N_{it} .

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

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

where Z_i is a vector of municipality-level characteristics that impact profitability in municipality i , e_i are unobserved factors in municipality i , and θ are unknown parameters of profit function Π_i . According to Manuszak & Moul (2008), the latent profit function Π_i should be interpreted as the reduced form of the expected present discounted value of profits resulting from competition between firms, once all entered in the market. We assume that profits are decreasing in N . 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:

$$N_{it} = 0 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{1}; \theta) + e_i < 0$$

$$N_{it} = 1 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{1}; \theta) + e_i > 0, \Pi_i(Z_i, N_{it} = \mathbf{2}; \theta) + e_i < 0$$

$$N_{it} = 2 \Leftrightarrow \Pi_i(Z_i, N_{it} = \mathbf{2}; \theta) + e_i > 0$$

Following Bresnahan & 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_i and Z_i

$$\begin{pmatrix} u_i \\ e_i \end{pmatrix} \sim N \begin{pmatrix} 0 & \sigma_u^2 & \sigma_{ue} \\ 0 & \sigma_{ue} & 1 \end{pmatrix} \quad (3)$$

From the distribution assumptions, it follows that

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

where

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

with $\phi(\cdot)$ and $\Phi(\cdot)$ representing the pdf and cdf of the standard normal distribution. 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.

The model is an ordered probit where the outcome variable describes the number of investors present in a municipality with the latent profit function

$$\Pi_i(Z_i, N_{inv}, e_i; \theta) = \beta Z_i + \Delta_1 * I(N_{inv} \geq 1) + \Delta_2 * I(N_{inv} \geq 2) + \nu_t + \varepsilon_i \quad (6)$$

Δ_1 measures the impact of the entry of a monopoly. Δ_2 presents the incremental impact of

adding one or more co-investors. $I(\cdot)$ is an indicator equal to one if the expression in parentheses is true. Time fixed effects are controlled by the quarter indicators (ν_i).

The functional form for FTTH quarterly coverage can be expressed as:

$$dcovFTTH_i = \lambda X_i + \gamma_1 I(N_{inv} \geq 1) + \gamma_2 I(N_{inv} \geq 2) + \sigma_{ue} h(N_{inv}, Z_i; \hat{\theta}) + \varepsilon_i \quad (7)$$

where γ_1 measures the impact of single investment on coverage. 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 equation (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 households which measures the market size. The second exogenous variable is the share of apartment housing, which is the proxy of deployment cost. The third exogenous variable is the distance to MDF, which represents the quality of ADSL speed.

6 Main results: No impact of coinvestment on the speed of FTTH municipal coverage

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 coverage regression with OLS and a two-stages 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. Profits and deployment costs in any municipality depend on a large number of factors, including consumers' willingness to pay for FTTH, switching costs of technological migration from ADSL to FTTH and reusable civil works. In general, civil works are owned either by co-investors themselves or by other owners such as the electricity company or municipalities. Indeed, the existing civil works enable investors to reduce their

FTTH deployment costs. Unfortunately, we cannot obtain or estimate many of these factors and rely primarily on the observed municipality characteristics. We estimate different alternate models to describe the factors that affect investors' entry decisions. Most parameter estimates seem reasonable and in the correct direction.

Table 3: Parameter estimates from entry model

VARIABLES	nb_investor
nbhouse	0.043*** (0.005)
share_apartment	2.170*** (0.139)
distanceToMDF	0.018*** (0.001)
XDSLlineB	15.367*** (1.646)
income	11.917*** (3.718)
density	0.060 (0.037)
education	-0.022 (0.169)
cable	0.085 (0.057)
Fixed effect firm 1 Δ_1	2.362*** (0.104)
Extra-effect firm 2 Δ_2	3.297*** (0.109)
Observations	45,686
Robust standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

The results from the first-stage entry model show some demand and cost factors, such as three exogenous variables that only enter in the entry model: number of households, share of apartment housing, and distance to MDF. First, the profitability of a market increases with market size, which is captured by number of households. 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 households, share of apartment housing, and distance to MDF are all positive.

In general, the control variables have the expected sign. The estimate for the number of business copper lines is positive, suggesting that the presence of business XDSL lines captures attractiveness of municipality for investment entry. Similarly, the positive coefficient for the average income suggests that profitability is higher in more affluent municipalities. Finally, the

estimates for population density, education level and presence of cable access are not significant. The estimate of the single investment effect, Δ_1 , suggests that the entry of FTTH triggers the migration from ADSL to FTTH and reduces a single investor's broadband profits, related 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.

The first-stage entry estimates, while interesting on their own, are used primarily as a tool to correct potential endogeneity in the FTTH coverage regression. Our main objective is to study the relationship between coverage and co-investment. In the following subsection, we first consider the investment entry exogenous and then endogenous by using OLS and then two-stage control-function regression, respectively.

6.2 Positive impact of co-investment on FTTH adoption and on competition

Under the assumption that the co-investment variable is exogenous, we first conduct an OLS regression. Our data include the FTTH quarterly coverage and the investment entry (0/1/2+ investors) for each municipality from 2015Q3 to 2018Q3. The dummy "FTTHEntry" corresponds to the municipalities with at least one investor. The dummy "co-investment" is equal to one for the municipalities with at least two investors. We control for the municipality-level socio-demographic variables. The municipality fixed effect and the time fixed effect are introduced in panel fixed effect specification.

Table 4: FTTH coverage regression

VARIABLES	Estimates without Pooled OLS dcovFTTH	correction Panel FE dcovFTTH	Estimates with correction second.stage dcovFTTH
FTTHEntry	0.057*** (0.001)	0.082*** (0.002)	0.032*** (0.002)
co-investment	0.025*** (0.002)	0.031*** (0.002)	0.003 (0.003)
XDSLlineB	-0.081*** (0.023)	0.084 (0.136)	0.110*** (0.025)
income	0.408*** (0.066)	0.030 (0.150)	0.181*** (0.057)
density	-0.010*** (0.001)	0.027 (0.024)	-0.002*** (0.001)
education	-0.003 (0.003)	0.003 (0.011)	0.007*** (0.002)
cable	0.004*** (0.001)	-0.010 (0.010)	0.007*** (0.001)
quarter fixed effect	Y	Y	Y
municipality fixed effect		Y	
region fixed effect	Y		Y
hazard			0.022*** (0.002)
Constant	-0.004*** (0.002)	-0.016 (0.012)	
Observations	45,686	45,686	45,686
R-squared	0.256	0.220	0.271
Number of id		3,573	

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

We present the results from regression without correction for 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. The left panel in Table 4 suggests a positive correlation between the co-investment entry and FTTH quarterly coverage. More specifically, the FTTH coverage rate is improved for co-investment entry, by an additional quarterly coverage of 2.5% for the pooled OLS estimator and of 3.1% for panel fixed effect estimator. However and as mentioned above, co-investment is not randomly assigned among municipalities but rather strategic decisions made by co-investors that evaluate FTTH demand and deployment cost. Unobserved FTTH demand and deployment cost shocks in a municipality might influence not only the FTTH coverage but also the co-investment entry. For example, municipalities with unobserved high costs are likely to have lower coverage and be failing to attract co-investment entry. In this case, the OLS regressions of FTTH coverage on the co-investment lead to the inference that high coverage is associated with the presence of co-investment. However, this

finding may partially be driven by unobserved costs. Similarly, unobserved positive demand shocks may result in higher coverage and an unusual presence of co-investment in a municipality, in which case the impact of co-investment on coverage may be overestimated. In addition, even with a panel estimator, one must still be concerned with whether the changes in the unobserved deployment cost (or demand) for the coverage regression are correlated with the change in co-investment decision. The deployment cost could logically increase over time since the coverage starts with the easiest areas with a lower cost (high-density and high share of apartment housing). Over time, the deployment will be increasingly expensive (the low-density individual houses have a much higher cost than the high-density apartments). The panel data approach does not resolve the concern when time-varying deployment costs and are correlated with the co-investment decision at each quarter for the new area concerned.

Therefore, the assumption that the co-investment variable is exogenous can be violated due to the presence of unobserved FTTH demand and deployment costs that are not adequately controlled for by the inclusion of time-varying control variables as well as municipality and quarter fixed effects. We use a two-stage control-function estimation to address the endogeneity of the FTTH investment decision. By 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 co-investment is no longer significant on FTTH quarterly coverage. The results show a significant bias in the co-investment parameter from the model that treats FTTH investment entry as exogenous. Excluding the correction term, co-investment is more efficient than single investment, with an additional coverage of +2.5% (or 3.1% in panel fixed effect specification). This is due to selection bias. FTTH co-investors choose municipalities that are easier to cover i.e., larger municipalities with a higher share of apartment housing. With the correction term, co-investment no longer has a significant advantage over the period studied. This finding is consistent with the notion that unusually attractive demand and low costs encourage FTTH investment entry while also supporting higher deployment progression.

7 Additional estimation results: Positive impact of co-investment on FTTH adoption and competition

Until now, we have estimated only the impact of co-investment on FTTH coverage. The FTTH adoption rate is determinedly conditioned by FTTH coverage. Moreover, a co-investor, by investing in FTTH, hopes to obtain the subscription of customers to FTTH. In this section, we focus on the impact of FTTH co-investment on FTTH adoption as well as on broadband market competition.

7.1 Positive effect of co-investment on FTTH adoption

In this subsection we study how co-investment affects the FTTH adoption. Recall that the FTTH adoption rate is defined as the ratio of the total number of FTTH customers to the number of connectable households. Increasing the FTTH adoption rate remains a challenge for all FTTH operators. The adoption of FTTH may depend on several factors. First, a consumer can adopt FTTH if and only if his house is already connected to the FTTH network. Second, since most consumers already have ADSL access, the migration from ADSL to FTTH may be motivated or slowed down not only by the willingness to pay for FTTH, but also by the switching cost of technological change or the switching cost of the Internet provider change. In the case of co-investment, we expect the switching cost of Internet provider change 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 face a double switching cost, related to change of technology and provider, and may have more obstacles to migrating from ADSL to FTTH. We run the regressions following Equation 7 by replacing “dcovFTTH” with “adoption”, without and with correction term derived from the first-stage entry model regression. The variable “co-investment” corresponds to the presence of co-investment on at least one PM before the quarter t . The adoption is different from the coverage. The quarterly FTTH coverage in quarter t is related to only the new lines deployed in quarter t . The number of FTTH adoption corresponds to all FTTH subscribers from all deployed FTTH lines since the

starting point of deployment⁸, and not just from newly deployed lines. These regressions include the same set of explanatory variables as those in Table 4.

Table 5: FTTH adoption regression

VARIABLES	Uncorrected adoption	Corrected adoption
FTTHEntry	0.169*** (0.009)	0.146*** (0.013)
co-investment	0.073*** (0.008)	0.076*** (0.009)
XDSLlineB	-0.309** (0.142)	-0.164 (0.115)
income	1.455*** (0.379)	1.375*** (0.303)
density	-0.021*** (0.005)	-0.016*** (0.004)
education	-0.021 (0.017)	-0.015 (0.014)
cable	-0.014** (0.007)	-0.010 (0.006)
hazard		0.013** (0.006)
quarter fixed effect	Y	Y
region fixed effect	Y	Y
Constant	-0.023** (0.009)	-0.024*** (0.008)
Observations	8,973	8,973
R-squared	0.389	0.390

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

Both OLS, two-stages with entry model, suggest that co-investment leads to higher FTTH adoption (+7,6%). This result is intuitive since Orange’s ADSL customers and co-investors’ ADSL customers migrate respectively to Orange’s FTTH offer and co-investors’⁹ FTTH offer without provider switching. The addition of both migrations favors a more efficient FTTH adoption.

7.2 More intense competition on broadband market with co-investment

In this subsection, we explore how broadband market competition is affected by co-investment. The broadband market in France consists mainly of ADSL and FTTH offers. The subscription

⁸A consumer could subscribe to FTTH in quarter t on a FTTH line deployed in quarter t, t-1, t-2 ... until t0, the starting quarter of FTTH deployment. Because the migration from ADSL to FTTH is neither automatic nor mandatory.

⁹The three FTTH co-investors are also LLU (Local Loop Unbundling) operators, i.e. Orange’s ADSL competitors.

to ADSL is still dominant over FTTH. The ADSL market is quite competitive with a very competitive tariff, among the lowest in Europe. Orange has a market penetration of around 40% on ADSL offers. Since ADSL and FTTH are substitutes, consumers are gradually migrating from ADSL to FTTH so that the copper network is scheduled to be replaced by FTTH network. The objective of the regulation is to guarantee a satisfactory level of competition during and after the transition from ADSL to FTTH. For this we measure at the end of each year the broadband market competition by the broadband market penetration held by Orange, which is the incumbent of the copper network and also the largest FTTH investor. The variable “co-investment” corresponds to the presence of co-investment on at least one PM in the year. We run the regressions following Equation 7 by replacing “dcovFTTH” with “MSBBOrange” (Orange’s broadband market penetration), without and with correction term generated by the first-stage entry model regression. These regressions include the same set of explanatory variables as those in Table 4 and 5.

Table 6: Competition regression (Orange’s broadband market)

VARIABLES	Uncorrected MSBBOrange	Corrected MSBBOrange
FTTHEntry	0.013** (0.006)	-0.007 (0.006)
co-investmnty	-0.036*** (0.005)	-0.078*** (0.008)
XDSLlineB	0.196 (0.181)	0.468** (0.188)
income	3.638*** (0.429)	3.368*** (0.407)
density	-0.050*** (0.005)	-0.037*** (0.005)
education	0.110*** (0.017)	0.121*** (0.016)
cable	-0.124*** (0.007)	-0.114*** (0.007)
hazard		0.038*** (0.005)
year fixed effect	Y	Y
region & department fixed effect	Y	Y
Constant	0.278*** (0.015)	0.285*** (0.014)
Observations	10,500	10,500
R-squared	0.512	0.520

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

Without the correction term, pooled OLS regression shows that Orange is gaining in broad-

band market penetration in municipalities with Orange investment alone, but loses 3.6% in municipalities with co-investment. With the correction term, Orange’s broadband market penetration is not impacted in the municipalities with Orange investment alone and loses 7.8% 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, the Orange 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 broadband market penetration may fall. This is what we found in Table 6, both with uncorrected and corrected regressions.

8 Conclusions

The aim of this paper is to assess whether the FTTH co-investment framework that was introduced on the French market in 2011 and supported in the new EECC increases coverage, adoption and competition or whether the opponents’ criticisms regarding the risks of re-monopolization, low investment and limited adoption are confirmed. We address this issue by providing empirical evidence on the impact of co-investment on actual FTTH coverage, adoption and broadband market competition. We utilized several French municipality-level datasets that provide data for the period 2015-2018. During this period, co-investment on FTTH deployment was introduced in less dense municipalities (ZMD and AMII) and has rapidly developed.

We built an original dataset that include the quarterly FTTH coverage, investor entry, FTTH adoption and Orange’s broadband market penetration. First, we find significant determinants of investor entry that are related to FTTH demand and cost factors. Second, by ignoring the endogeneity of investor entry, the pooled OLS and panel fixed effect regressions show that the co-investment is more efficient than the single investment due to the selection bias of co-investors. However, the two-stage control-function approach, by overcoming the selection bias, suggests that the co-investment has no significant advantage on FTTH quarterly coverage, since

the full coverage in five years is fixed by the regulator. We also find that the co-investment entry increases FTTH adoption and broadband market competition. Therefore, the European Commission appears to be justified in proposing the draft Telecom Code proposal that includes a co-investment regulatory regime as an alternative to the classical access regulation regime.

This paper's analysis has some limitations that could be addressed in future work. First, our results hold for France which does not face the same circumstances as other European countries. Second, the efficiency of RIP deployment, with the contribution of public investment, for areas less dense than AMII areas is not investigated. The next step could be to study other European countries, as well as to extend the study to the efficiency of public investment.

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