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Estimating the impact of co-investment in fiber to the home coverage*

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Abstract

Does co-investment enhance fiber to the home (FTTH) coverage? We combine several French municipality-level datasets to answer this question. We find that a 1% co-financing share by co-investors leads to an increase in FTTH coverage by 0.8% during the 2013-2016 study period and a 0.6% annual progression. This result is robust to changes in the specification and instrument and is consistent with the outcome of a simple difference-in-differences analysis comparing FTTH coverage in co-investment areas with areas with no co-investment *ceteris paribus*. In addition, we find that a 1% co-investment increases FTTH adoption among Orange's fixed broadband customers by 1.2% and decreases Orange's total fixed broadband penetration for asymmetric digital subscriber lines (ADSL) plus FTTH coverage by 1.1%, which benefits competitors. Our findings confirm that co-investment supports the policy objectives of coverage, adoption and competition and should be supported by regulation.

Key Words: *FTTH coverage; co-investment*

JEL Classification: L43, L51, L96

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1 Introduction

Should telecommunications operators be encouraged to engage in co-investment as a way to reconcile competition and investment in terms of very high connectivity network (VHCN) coverage? This article contributes to answering this question by providing detailed empirical estimations of the influence of co-investment on FTTH coverage in the fixed broadband market.

The regulation of access obligation regarding the physical infrastructure of an incumbent telecom operator is not new in European telecommunications policy. The 2002 European regulatory framework considers that opening telecom markets to competition requires not only eliminating legal barriers to entry but also providing access to the existing physical infrastructure of former monopolies, at least as long as no competitive alternative for this infrastructure exists. Whether this access obligation has encouraged investment, as it supports investment in assets that complement the existing infrastructure, or has deterred investment, as it discourages investment in asset substitutes to the existing infrastructure, has been hotly debated since this regulation was introduced. Regulators use the so-called "ladder of investment theory" articulated by Cave (2006) in a heuristic attempt to manage this dilemma: the physical frontier of access obligation is supposed to move over time, following (or preceding) the physical extension of alternative infrastructures deployed to compete with the infrastructure of the incumbent operator.

The ladder of investment theory addresses the investment incentives of alternative operators but does not consider how the investment incentives of the former monopoly for its infrastructure, which are subject to access obligation, would be affected. This was not a real concern for public authorities in the decade of 2000-2010 because the historical copper infrastructure was considered to be sufficient for supporting the type of broadband access required by the market. However, this issue started to be considered seriously around 2010 when it became clear that the historical copper infrastructure on which most of the broadband deployment and competition had been developed could not indefinitely support the growing demand for traffic (and speed) and that Europe was lagging behind other regions of the world in terms of VHCN coverage. Since then, determining how regulation can articulate incumbent and entrant investment incentives has become the core of the regulatory debate regarding access.

This debate now concentrates on which access obligations should be imposed on newly deployed fiber infrastructure. In areas where the business case of broadband access can support several parallel competing infrastructures, complete deregulation can take place¹, as access is no longer required to safeguard effective competition. However, where the business case of broadband cannot support several parallel infrastructures, this question remains unanswered, and public authorities face a new dilemma:

- On one hand, regulating access to new fiber investment can deter investment both from the incumbent (which cannot gain a competitive benefit from its investment) and from entrants (which are better-off relying on the incumbent's investment than taking the risk of investing themselves). Mitigating access obligations by setting higher access prices (the so-called "risk premium") does not solve this problem. First, the profitability of the incumbent's investment is subject to the discretion of the regulator. Second, finding the right price for such regulated access equates to squaring the circle because if the access price is high, then retail prices will also be high; otherwise, the regulation would result in an illegal margin squeeze for the competitors, and fiber services do not attract customers using copper access. This process would lead to a commercial failure of retail services based on the fiber infrastructure. Alternatively, if the access price is low, then non-investors are better off than investors because they benefit from the investment without being subject to the risk or even the cost of the investment; therefore, potential investors have no incentive for investing.
- On the other hand, the absence of access obligation when effective infrastructure-based competition is not sustainable may lead to re-monopolization when an increase in customers' demand for speed and volume leads most consumers to switch from legacy infrastructure-based broadband services to fiber-based services with very high broadband penetration. The risk of re-monopolization is clear when the expected revenue from the access market allows only the roll-out of one single VCHN. The issue of access obligation is also relevant when two infrastructures can co-exist, as duopoly is generally considered to be prone to

¹Except for access to civil works, ducts and poles.

tacit collusion and therefore may not ensure effective competition.

Europe has been looking for intermediate solutions between these two extreme options, pure access and/or no access, based on the principle of risk-sharing, through which access seekers are required to share the investment risk of rolling out VHCN networks to gain access to this new infrastructure. The intuition behind proposing risk sharing is that, when demand is insufficient to sustain infrastructure competition, but more than one provider should operate to safeguard competition, there is still a reward for investment because only those who participate in the investment benefit from the new infrastructure.

The principle of risk-sharing was introduced in the 2009 update of the European telecom regulatory framework. The risk-sharing arrangement may take numerous forms such as value, volume or time commitments, or upfront payments, but the simplest and the most intuitive 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 National Regulatory Authority encouraging and sometimes using 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 examples, co-investment has been endorsed by the European Commission as a relevant option for conciliating investment and competition. The European Commission included in its proposal for a new European Economic Communications Code (EECC), which was published in September 2016, Article 74, through which incumbent operators providing their competitors appropriate forms of co-investment in their newly deployed fiber infrastructure could be exempt from other forms of access obligations. This proposal has been 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, which survived the legislative process.

The objective of this paper is to empirically assess whether such a co-investment scheme will lead to the expected outcomes of more coverage with the same level or increased competition or whether the criticisms of the opponents against co-investment will be confirmed. We address this issue by providing empirical evidence on the quantitative causal impact of co-investment in the actual roll-out of FTTH networks. We use a natural experiment of the impact of co-investment in local coverage, as well as adoption and competition, from 2013 to 2016 in French municipalities in zones moins denses "ZMD" areas", which refer to less dense areas.

This analysis is relevant because the co-investment scheme that is available in these areas in France is the model for the co-investment scheme considered to be appropriate in Article 74 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 2013 to 2016, on the adoption of broadband and fiber services in these municipalities, and on the level of co-investment in these municipalities. By controlling variables and using appropriate instruments, we are able to identify how co-investment influences the coverage rate of FTTH networks in these municipalities. We are able to show that during the study period, a 1% co-investment causes on average an increase of 0.8% in FTTH coverage and an increase of 0.6% in the annual progression. Our results also confirm that a 1% co-investment enhances adoption (1.2% more penetration of Orange's FTTH access service) and competition (1.1% less total penetration of Orange's ADSL+FTTH access services) where it takes place.

Based on these figures, the conclusion of our empirical study is that co-investment actually leads to increased FTTH coverage, as well as increased adoption and competition; therefore, co-investment should be encouraged by public authorities. To the best of our knowledge, this article is the first to provide empirical evidence on the specific impact of co-investment schemes on broadband access market outcomes.

The remainder of the 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, which is applicable to the territory 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 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 two streams of the literature concerning the economics of telecommunications; one stream specifically analyzes co-investment and more generally, upstream cooperation between downstream competitors. The second stream analyzes the impact of mandatory access regulation in the telecommunications industry.

The first stream of the literature on upstream cooperation between downstream competitors mostly includes theoretical papers. The study most closely related to our work is "Cooperative Investment, Access, and Uncertainty" by Bourreau *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 and 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, in particular when demand is uncertain.

In addition to this first reference, the Institute of Industrial Economics (IDEI) policy report "Cooperation Between Firms for Infrastructure" by Sand-Zantmann (2017) reviews the theoretical literature addressing the issue of upstream cooperation between firms that compete downstream. In Sand-Zantmann (2017), author includes in this review, in addition to Bourreau *et al.* (2018), the seminal article by d'Aspremont & Jacquemin (1988) "Cooperative and Non Cooperative R&D in Duopoly with Spillovers", as well as more specific telecommunications papers: "Investment Sharing in Broadband Networks" by Cambini & Silvestri (2013) and "Investment under Uncertainty and Regulation of New Access Networks" by Inderst & Peitz (2014). In his review, Sand-Zantman derives the general policy conclusion that if investing is necessary,

then firms that benefit from the investment should be those that are subject to the investment risk. This conclusion is in line with the more specific conclusion documented in Bourreau *et al.* (2018) that the co-investment regime that includes risk-sharing by the access seeker dominates regimes that include standard access without any risk.

Our paper adds empirical results to the 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 and 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), "Investment Sharing in Broadband Networks" by Cambini & Silvestri (2013), 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".

Bourreau *et al.* (2017) wrote the working paper "Unbundling the Incumbent and Entry into Fiber: Evidence from France", which analyzes the impact of the presence of copper and cable alternative operators on entry into the FTTH market. This study focuses on investment by an entrant at the municipality level, independent of the actual coverage in each municipality.

Our paper is the first empirical paper to specifically assess a co-investment regime and focus on detailed coverage, penetration, competition and co-investment data at the municipality level.

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

The empirical analysis presented in this paper was conducted in areas subject to the regulatory framework of FTTH in so-called ZMD areas where coverage is ensured by private investment (the so-called "AMII" zone).

First, we describe the FTTH regulatory framework imposed on the less dense areas. Sec-

ond, we explain how the AMII zone of private investment has been defined and its proportion compared to other areas in France.

3.1 Co-investment regulation for FTTH in ZMD areas

Describing the current regulatory framework of ZMD areas is necessary because the terms of the co-investment arrangements have been defined by the French FTTH regulatory framework. This regulatory framework is 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 to say outside Very Dense Areas, corresponding the rest of France, which represents 83% of the population (see https://www.arcep.fr/uploads/txgsavis/10_1312.pdf).

Here, we only summarize the rules for less dense areas defined in Decision 2010-1312 because they apply to the geographical areas included 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 the EECC.

In the less dense areas covered by our study, co-investment concerns local technical areas corresponding to a concentration point ("Point de Mutualisation" (PM)) serving at least 1000 customers or at least 300 customers if the investing operator provides an appropriate dark fiber backhaul at a cost-oriented price.

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 can do so by purchasing 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 in FTTH infrastructure and on how co-investment opportunities should be priced: https://www.arcep.fr/uploads/tx_gspublication/RecoARCEP_mutualisation_fibre_01.pdf

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 investment in FTTH access networks will be insured by private operators (including the incumbent operator Orange) have been defined and its corresponding share compared to all of France.

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.

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

The French authorities included areas that were incorporated into the response of least one private operator to this call in the so-called "AMII areas". French authorities consider that in other areas, coverage by FTTH should be open to public intervention and public subsidies: these are referred to as *reseaux 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 that are outside very dense areas.

Orange and SFR were the only two operators to make the significant commitment to cover AMII areas. In practice, during the period studied in our article (2013-2016), an overwhelming proportion of the AMII areas have been covered by Orange, notably, because in the meantime, SFR has been acquired by Numericable, the French cable operator.

Our empirical study is limited to AMII areas that are 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 4 years, from 2013 to 2016. We link these datasets by using unique identifiers for each municipality. For each municipality, we obtain information on the co-financing share of private FTTH co-investors. FTTH coverage is measured by the number of Orange fixed broadband customers⁴, the adoption of FTTH by Orange's customers, Orange's fixed broadband penetration (ADSL+FTTH), and socio-demographic characteristics⁵.

The first database that includes information on FTTH co-investment, FTTH coverage, FTTH adoption by Orange's customers and fixed broadband penetration was obtained from Orange. To encourage investment in FTTH infrastructure and stimulate competition, the regulator introduced co-investment by private operators for ZMD AMII municipalities (less dense municipalities with potential economic profitability). At the end of 2016, 594 municipalities (cf.

³We obtained information on 3573 of the 3616 ZMD AMII French municipalities in 2016. Some of the socio-demographic variables are not available for the remaining 43 municipalities.

⁴For notational simplicity, hereafter, the term 'FTTH coverage' is used.

⁵to avoid simultaneity issues, we use lagged values for socio-demographic characteristics before 2013, i.e. from 2009 to 2012.

Figure 1) saw the arrival of co-investment and experienced a significant increase over time. The average co-financing share is approximately 12% with the highest participation rate of 30%. The remaining share is de facto financed by Orange. In 2016, Orange was not involved in the deployment of fiber in 97 municipalities. Hence, the deployment of fiber in these municipalities was carried out by Orange’s competitors.

In this database, FTTH coverage rate is defined as the ratio of the number of Orange’s fixed broadband customers eligible for FTTH access to the number of houses in the municipality. Among Orange’s customers eligible for FTTH access, three types of deployment are included. The first deployment includes co-investment from both Orange and Orange’s competitors. The second deployment includes only Orange’s FTTH deployment. The third deployment includes competitors’ deployment for which Orange has wholesale agreements to sell the competitors’ FTTH access to Orange’s customers. As all deployments, i.e., both Orange’s and its competitors’ deployments, cover all the houses and not just their own customers, in our dataset, the FTTH coverage rate is measured as a proportion of Orange fixed broadband customers due to multi-operator deployments. We compared the FTTH coverage rate measured by Orange fixed broadband customers in our database with the aggregate FTTH coverage rate that includes all operators at the municipality-level, which was published by ”France Tres Haut Debit” for the period 2015- 2016⁶. In our database, a slightly lower coverage rate is observed because the FTTH coverage published by ”France Tres Haut Debit” only considers fiberization from the concentration point to the building’s entrance, while Orange’s FTTH coverage takes into account the complete fiberization from the operator’s local exchange to the building’s entrance⁷.

The adoption rate is defined as the ratio of the number of Orange’s FTTH customers to the

⁶”France Tres Haut Debit”’s FTTH coverage is defined as the ratio between the number of houses that can connect to FTTH to the number of houses in the municipality in 2013. To compare the FTTH coverage measured by the number of Orange fixed broadband customers and ”France Tres Haut Debit”’s FTTH coverage, Orange’s FTTH coverage is calculated as the ratio of the number of Orange broadband customers eligible for FTTH to the number of Orange’s fixed customers (PSTN, ADSL and FTTH).

⁷Horizontal fiberization has two parts: The first part is the installation of the fiber optic from the operator’s optical local exchange to the concentration point. The second part is the installation from the concentration point to the building entrance box. The fiberization from the concentration point to the building entrance box is shared by co-investors in the case of co-investment. In the case of single operator deployment, both parts of horizontal fiberization are supported by the operator. For Orange’s FTTH coverage, both parts of horizontal fiberization are supported. For the multi-operator FTTH coverage published by ”France Tres Haut Debit”, only the second part of horizontal fiberization is taken into account.

number of houses in the municipality. Consequently, FTTH adoption rate is constrained by the FTTH coverage rate.

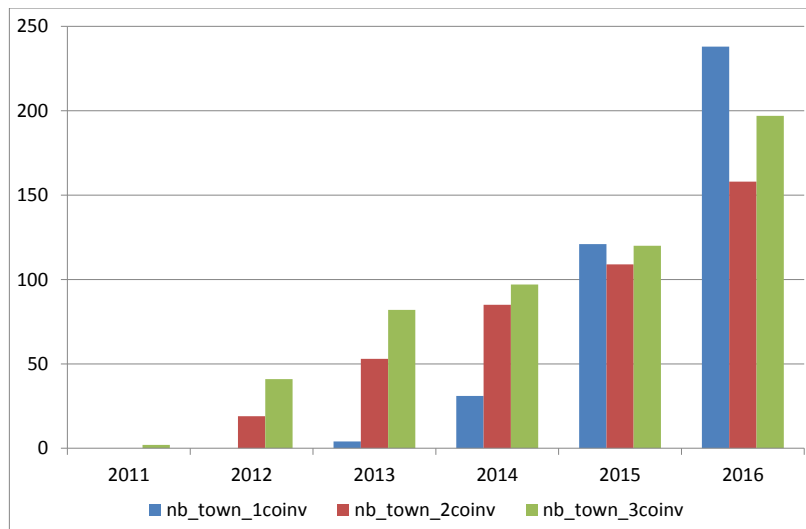


Figure 1: Evolution of FTTH co-investors in ZMD area

The second dataset contains information on municipality-level socio-demographic characteristics and is obtained from administrative registers provided by the national statistical office (INSEE) or the French telecom regulator (ARCEP). Specifically, we use a longitudinal database for the period 2009-2012. The average income, the unemployment rate, the education level, the number of housings, the share of apartment housing, the number of copper lines owned by the firms, the share of housing eligible for cable access and population density are used as controls for the socio-demographic characteristics of the population. 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 housing eligible for cable access at 30Mb/s (basic cable speed) at the municipality-level is provided by the French national telecommunications regulator ARCEP. From 2013-2016, 37% of cable access was upgraded from 30Mb/s to 100Mb/s during the same period. The cable coverage rate, without taking into account the speed upgrade, is quite stable over time.

Additional municipality-level variables used to construct an alternative instrument, such as the number of mobile antennas owned by each operator from 2013-2016, are provided as open data by the Agence National des Frequences (ANFR). This dataset includes information on mobile technologies (2G, 3G or 4G), the frequency bands used by each technology, the mobile operator⁸ and the date the antenna began service for each municipality.

Table 1 displays some statistics on ZMD municipalities covered by FTTH.

Table 1: Summary statistics of municipalities covered by FTTHs from 2013 to 2016

year	Nb FTTH municipalities(ZMD)	with co-investors	cofinancing	coverage	adoption
2013	167	139	14.5%	7.8%	1.9%
2014	275	214	13.9%	9.3%	4.4%
2015	479	351	11.5%	11.7%	8.1%
2016	863	594	10.6%	11.9%	8.3%

Table 2 shows that among all the co-investment municipalities, 75% of these municipalities included the lowest co-financing share of 5% per co-investor. More precisely, this 75% is composed of three subsets. The first subset is 24% and includes municipalities where only one co-investor chose to participate at a minimum of 5%. In the same way, the second sub-set represents 22% of municipalities for which there are two competitors co-investing in 5% of the capacity. Finally, the third sub-set represents 29% of municipalities, for which three competitors co-invested in 5% of the capacity.

Table 2: 75% of co-financing municipalities with 5% financial contribution per co-investor

co-financing share with	1 co-investor	2 co-investors	3 co-investors	Total
5%	24%	0%	0%	24%
10%	5%	22%	0%	26%
15%	1%	6%	29%	36%
20%	0%	1%	6%	7%
25%	0%	3%	2%	5%
30%	0%	0%	1%	1%
Total	30%	31%	39%	100%

⁸In France, the four fixed broadband operators, Bouygues Telecom, Free, Orange and SFR, are also mobile operators.

In Table 3 we present the summary statistics of the main variables for 3573 ZMD AMII municipalities. 'Cofinancing' represents the co-financing share of the co-investors (the sum of the co-financing share of all Orange's co-investors). FTTH adoption is only observed for Orange's customers.

Table 3: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
cofinancing	1269	0.123	0.056	0.050	0.300
coverage	14054	.0126	.0497	0	.8040
d.coverage	10528	.0051	.0232	0	.5391
adoption	14054	.0066	.0376	0	.7263
Paf	14050	.3378	.1144	0	.9444
l4income (keuros)	14054	.0270	.0076	.0118	.1383
l4unemployment	14054	.0965	.0435	0	.3435
l4edu	14054	.6779	.1812	.2335	1
l4density (000)	14054	.3625	.6460	.0028	7.1812
l3apartment	14054	.2055	.2218	0	.9492
cable30	14054	.1394	.3139	0	1
l4lineB	14054	.0116	.0121	0	.1292
rnbsiteCO	14054	.4275	.3499	0	1
dnbsiteCO	14054	3.625089	11.87749	-79	345
housings	14054	3478.687	7389.738	43	99692
year	14054	2014,5	1	2013	2016

5 Econometric model

This paper primarily aims to examine the extent to which the growth in FTTH coverage is causally affected by co-investment, especially by the co-financing share of co-investors. To test the effect of co-investment on FTTH coverage, we specify the following reduced form econometric model:

$$Y = \alpha s + \beta X + \epsilon \quad (1)$$

In equation (1), Y measures the FTTH coverage rate. s is our variable of interest, which represents the co-financing share of Orange's co-investors. X is a vector of municipality-level

socio-demographic characteristics, including the average income, the unemployment rate, the education level, the number of houses, the share of apartment housing, the share of housing eligible for cable access and population density. ϵ is a vector of unobservable parameters, including FTTH deployment costs.

We introduce municipality and year fixed effects into equation (1) to account for time invariant factors. The impact of co-investment on FTTH coverage is identified by variations in the coverage rates and the co-financing shares within municipalities and across municipalities. This strategy eliminates bias due to municipality-specific time invariant unobservable factors correlated with the co-financing share and FTTH coverage rates. The estimated equation can be expressed as:

$$Y_{it} = \alpha s_{it} + \beta X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

In equation (2), s_{it} represents the co-financing share of co-investors in municipality i in period t . The unobservable determinants of FTTH coverage that are fixed at the municipality level are controlled for through the municipality indicators (μ_i). Time fixed effects are controlled by the year indicators (ν_t), which also control for the unobserved factors affecting the likelihood of FTTH coverage that are common to all municipalities in a given year. We also introduce department-year interactions to investigate the importance of spatial heterogeneity. The ordinary least squares estimate of parameter α in equation (2) would be biased due to unobserved FTTH deployment costs. To identify the causal impact of co-investment on FTTH coverage, we implement a 2SLS estimation strategy by introducing instrumental variables for s_{it} . We use two variables as instruments for our variable of interest s_{it} :

- The first instrument is the dummy for the merge event between SFR (the 2nd largest mobile and fixed operator in France after Orange) and Numericable (France's unique cable operator) in November 2014.
- The second instrument is the ratio of the number of competitors' mobile antennas (Orange excluded) and total mobile antennas (Orange included) in the municipality.

The justification for the choice of these two instruments is detailed below.

To remain significant but at the same time satisfy exclusion restrictions, the chosen instruments must fulfill the following conditions: they must be correlated with the co-investment decisions of Orange's competitors in a given municipality without being correlated, excluding those co-investment decisions, with Orange's own coverage in this area. Fulfilling these conditions implies that the instruments do not measure some general exogenous characteristics of the municipality because they would not discriminate between Orange and Orange's competitors. Such general exogenous characteristics would apply equally to Orange and to its competitors and therefore it would not satisfy the exclusion restrictions, which explains why the geographical variations of the instruments must generate geographical variations in the decisions of Orange's competitors to co-invest, but they should have no direct influence on Orange's fixed FTTH local strategy. The following paragraph explains why these conditions are fulfilled for the two instruments we chose.

The first instrument is the dummy for the merger event between SFR (the 2nd largest mobile and fixed operator in France after Orange) and Numericable (France's unique cable operator, covering slightly less than 40% of households) in November 2014. This exogenous shock corresponds to time variations, which splits the study period in two sub-periods. The first sub-period ends in October 2014, before the merger. The second sub-period starts in November 2014, after the merger was approved by the French competition authority on October 30th 2014. For the full decision authorizing the merger, please see

http://www.autoritedelaconurrence.fr/pdf/avis/14DCC160decision_ersion_publication.pdf.

This exogenous shock strongly influenced the co-investment strategy of SFR and therefore the general level of co-investment because during the study period, SFR was the alternative operator most active in co-investment. Before the merger, SFR had an incentive to co-invest in all the municipalities. These incentives related first to the ability to be more competitive and attract new customers due to the higher level of quality that can be reached using the FTTH infrastructure. Second, these incentives related to the opportunity to provide FTTH its customers by unbundling the copper local loop of Orange, thereby reducing variable costs.

After the merger with Numericable, SFR no longer had an incentive to co-invest in FTTH in municipalities covered by the cable infrastructure of Numericable because after the merger, SFR

could use Numericable's infrastructure at nearly zero incremental cost for the merged entity and provide a service technologically similar in terms of speed and quality to the service provided using FTTH, at least for the customers during the study period. Hence, SFR stopped co-investing in FTTH after the merger in municipalities already covered by the cable infrastructure. Outside the cable footprint, the incentives for SFR to co-invest in FTTH have in theory remained as they were before the merger, although in practice, mergers usually generate transitory adjustments in organizations and governance, which may have indirectly impacted decision making within SFR.

The merger also had a second order impact on co-investment. Before the merger, Bouygues Telecom, the 3rd or 4th largest telecom operator in France (depending of the metric), had a commercial agreement with Numericable to sell retail service based on wholesale access to the cable infrastructure and did not use FTTH in areas covered by the cable infrastructure. After the merger, Bouygues Telecom changed its strategy and gradually switched to FTTH even in the cable area.

Hence, the merger had a clear impact on the FTTH co-investment strategy of Orange's competitors and therefore fulfils the first criterion of being an appropriate instrument.

The second criterion is the exclusion criterion: Could the SFR-Numericable merger have influenced Orange's FTTH deployment strategy independently of its impact on the co-investment strategy of Orange's competitors? This seems highly unlikely for the following reasons:

- The merger modified Orange's FTTH deployment costs through competitors' co-investment strategies in the cable areas,
- The merger did not modify Orange's demand prospects, other than differences in the competitive pressure in cable areas, resulting from the effects of the switch of SFR from FTTH to cable and that of Bouygues from cable to FTTH, which are conveyed through competitors' co-investment strategies.

The second instrument is the ratio of mobile antennas between the number of competitors' antennas (Orange excluded) and the number of total antennas (Orange included), which measures the density of the mobile physical infrastructures of Orange's competitors relative to the

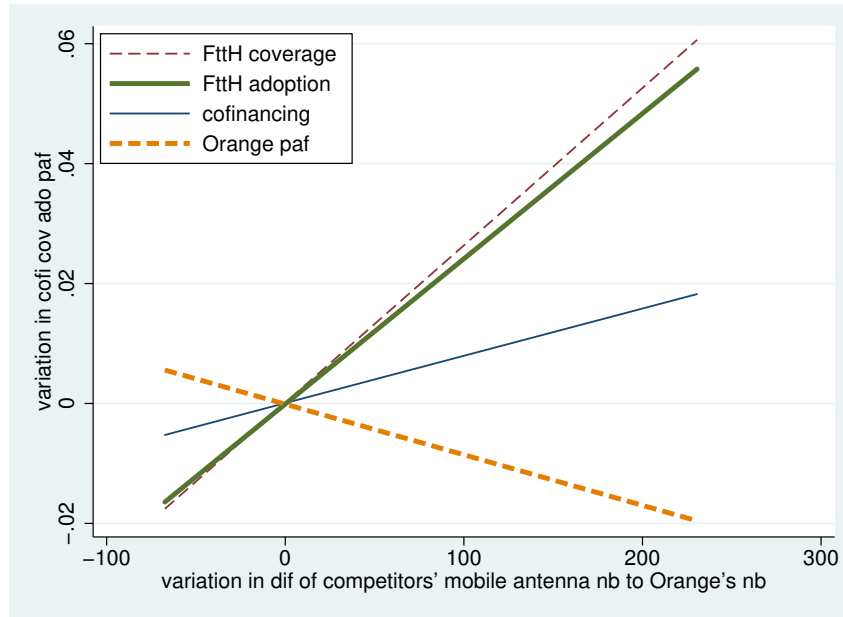
average density of all of the mobile physical infrastructures in each municipality. Therefore, this ratio indicates the extent to which Orange’s competitors may benefit from synergies between the fixed and mobile infrastructures in each municipality, which in turn influence their decisions regarding whether to co-invest in FTTH in each municipality. Therefore, this variable fulfills the first condition for being a good instrument.

This variable also fulfill the second exclusion condition for being a good instrument because it should not have any direct influence on Orange’s local FTTH coverage and commercial strategy:

- This variable should not influence the cost side because it has no influence on Orange’s FTTH cost in the municipality, which occurs because Orange is a former fixed incumbent operator, and its cost of rolling out FTTH in this municipality relates to its legacy fixed infrastructure, not to synergies with its mobile infrastructure.
- This variable should not influence the price and competition side either because the instrument has no direct influence on the local attractiveness of the fixed offers of Orange’s competitors. Local competition in the fixed market is determined by the fixed offers available locally and also by the non-local national characteristics of offers defined at the national level, which include fixed-mobile bundles. However, local competition in the fixed market does not depend on the local characteristics of mobile offers.

Hence, this instrument satisfies the exclusion restrictions. This identification strategy is illustrated in Figure 2. The linear fits of the first difference of the three dependent variables, the endogenous variable and the instrumental variable are used in Figure 2. These variables include two types of variations. The first type of variation occurs over time and is common to all the municipalities. The second type of variation is due to the heterogeneity of the municipalities such as their socio-demographic parameters. To obtain a variation regardless of the common time trend, we first exclude the time trend effects by regressing cofinancing, coverage, adoption, the instrumental variable and Orange’s fixed broadband penetration (ADSL+FTTH) on the time variable (year) and take the first difference of the residuals. We observe positive correlations between the variations in co-financing (and also for coverage and adoption) and the variations in the differences in the mobile antennas (between competitors and Orange). A negative correlation

Figure 2: Variations in the dependent variables and the endogenous variable as a function of variations in the instrument



is observed between the variations in Orange's fixed broadband (ADSL+FTTH) penetration and the variations in the differences in the mobile antennas (between competitors and Orange). Next, an econometric estimation is needed. The correlations shown in Figure 2 indicate that the co-financing share has a causal impact on FTTH coverage, adoption and fixed broadband competition, provided that the instrument and a change in this alternative instrument predict change in the co-financing share without affecting the dependent variables.

Now that we have developed two valid independent instruments, we will first use each one separately and observe that they lead to consistent outcomes. We will then show that they are independent; therefore, we can use them together to improve the accuracy of our estimations.

The reasoning developed above holds not only for Orange's FTTH local coverage at the municipality level, which is measured by the main variable analyzed in Section 6, but also for Orange's FTTH adoption rate and competitive intensity at the municipality level, for which complementary results are provided in Section 7.

6 Estimation results: positive impact of co-investment on FTTH coverage

This section presents the OLS and 2SLS regressions results, the first stage regressions results, the robustness checks and their policy implications.

6.1 OLS and 2SLS regressions

Under the assumption that the co-investment variables are exogenous, we first conduct an OLS regression. Table 4 shows that there is a positive and significant correlation between the co-financing share and the FTTH coverage rate. More specifically, the FTTH coverage rate is improved by 0.5% for every 1% co-financing effort. We control for the municipality-level socio-demographic variables, the municipality fixed effect and the time fixed effect.

The assumption that the co-investment variable is exogenous can be violated due to the presence of unobserved heterogeneity that is not adequately controlled for by the inclusion of time-varying control variables as well as municipality and year fixed effects. By using instrumental variable specification, the 2SLS estimates in Table 5 are significant and in line with the OLS estimates.

Compared to the OLS regression, the coefficient of the co-investment variable is higher than that for the previous estimation. OLS estimator underestimates α if the unobserved variables such as the FTTH deployment costs are negatively correlated with the co-investment variable. According to the 2SLS estimation, the FTTH coverage rate is improved by 0.8% for every 1% of co-financing effort. The specification with the 'sfricable' dummy variable as an instrument, the specification of 'rnbsiteCO', and the ratio of competitors' mobile antennas results in a similar coefficient for 'cofinancing'. We use both instruments in the same 2SLS regression. The coefficient remains very close to that for the 2SLS regressions when using each instrument separately. The confidence interval is reduced because the two instruments are orthogonal, and there is greater variability of the data. Since investment in FTTH is inherently a dynamic phenomenon, we also estimate the impact of co-investment on the progression of annual FTTH coverage (by replacing 'coverage' by the first difference 'd.coverage' in the estimation). The

regression result (last column of Table5) suggests that a 1% co-financing share by co-investors leads to an increase of 0.6% in the progression of annual FTTH coverage.

The 2SLS estimates pass all the standard statistical tests. In particular, we ensure that the dummy variable 'sfricable' and the ratio of the competitors' antennas have positive and significant effects on the co-investment variable. In addition, the first-stage F-statistics are well above the critical threshold of 10, and Stock and Yogo's weak instrument test statistic is also above its critical threshold. The Sargan Hansen test, which tests for over-identifying restrictions when two instruments are both used in the same 2SLS regression, is also satisfied. These outcomes support the use of the dummy variable for the SFR/Numericable merging event and the ratio of the competitors' mobile antennas as an instrument for co-investment.

Table 4: OLS regression results

VARIABLES	coverage
cofinancing	0.5186*** (0.011)
l4income	0.0981 (0.132)
l4unemployment	-0.0057 (0.023)
l4edu	0.0223*** (0.008)
l4density	-0.0558*** (0.015)
l3app	0.0431*** (0.016)
cable30	-0.0008 (0.005)
l4lineB	0.1976** (0.085)
year dummy	Y
year_dep	Y
Observations	14,054
R-squared	0.360
Number of municipalities	3,573
Standard errors appear in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$	

Table 5: 2SLS regression results

VARIABLES	IV1=sfrcable coverage	IV2=rnbsiteCO coverage	IV1+IV2 coverage	IV1+IV2 d.coverage
cofinancing	0.8124*** (0.125)	0.7567* (0.428)	0.8085*** (0.121)	0.6487*** (0.112)
l4income	0.1910 (0.131)	0.2080 (0.180)	0.1922 (0.131)	0.1825 (0.151)
l4unemployment	-0.0270 (0.026)	-0.0216 (0.048)	-0.0267 (0.026)	-0.0160 (0.030)
l4edu	0.0279*** (0.008)	0.0276*** (0.008)	0.0279*** (0.008)	0.0399*** (0.010)
l4density	-0.0532*** (0.016)	-0.0554** (0.022)	-0.0534*** (0.016)	-0.0168 (0.016)
l3app	0.0283 (0.017)	0.0310 (0.026)	0.0285 (0.017)	0.0104 (0.019)
cable30	-0.0026 (0.006)	-0.0023 (0.006)	-0.0026 (0.006)	0.0012 (0.005)
l4lineB	0.2136** (0.097)	0.2360 (0.191)	0.2152** (0.096)	0.1901 (0.123)
year dummy	Y	Y	Y	
year_dep	Y	Y	Y	
Observations	14,054	14,054	14,054	10,528
R-squared	0.307	0.321	0.308	0.210
Number of municipalities	3,573	3,573	3,573	3,573
First-Stage F-statistic	85.81	7.092	45.75	43.37

Standard errors appear in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

6.2 First stage: determinants of co-investment in FTTH

The panel regression of the first stage helps us understand the determinants of private operators becoming Orange's co-investors. The dummy 'sfrcable' is positive and significant. The cofinancing share increases by 0.57% after the SFR/Numericable merger. In particular, the merger has an impact on the number of newly built "PMs" ("Point de Mutualisation") by distinguishing between the municipalities covered by cable and those that are not. The total number of new "PM" increases over time in both areas that are covered by cable and those that are not. However, if we look at the results in more detail, some of the co-investors reduce their propensity to co-invest in new "PM" after the merger, especially in the areas covered by cable. Others continue their

co-investment without considering the merger. These variations lead to temporal and spatial variability in FTTH coverage. The coefficient of 0.0069 for the variable 'rnbsiteCO' means that the ratio of the competitors' mobile antennas in a municipality enhances the co-financing share of co-investors. Each 1% increase in the ratio of the competitors' mobile antennas leads to an increase of 0.0069% in the co-financing share. The higher the share of apartment housing and the number of business copper lines is, the more attractive the municipality is for co-investment. As we introduce the municipality and time fixed effects, the effects of income, the level of education and population density are also partly captured by these fixed effects.

Table 6: First stage regression: FTTH co-investment determinants

VARIABLES	cofinancing	cofinancing
sfricable	0.0057*** (0.001)	
rnbsiteCO		0.0069** (0.003)
l4income	-0.1221 (0.117)	-0.1187 (0.117)
l4unemployment	0.0618*** (0.020)	0.0616*** (0.020)
l4edu	-0.0184*** (0.007)	-0.0183*** (0.007)
l4density	-0.0349*** (0.013)	-0.0343*** (0.013)
l3app	0.0499*** (0.014)	0.0496*** (0.014)
cable30	0.0060 (0.005)	0.0058 (0.005)
l4lineB	0.1939*** (0.074)	0.1906** (0.074)
year dummy	Y	Y
year_dep	Y	Y
Observations	14,054	14,054
R-squared	0.106	0.107
Number of municipalities	3,573	3,573
Standard errors appear in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$		

6.3 Robustness check

We test the robustness of the main estimates with respect to the estimation strategy. First, we implement 2SLS estimators by replacing the variable of interest 'cofinancing' with alternative co-investment variables. Second, we run difference-in-differences regressions by using co-investment entry in FTTH municipalities to construct a 'treatment group' and a 'control group'.

■ Alternative variables characterizing FTTH co-investment

We created two alternative variables of interest that similarly characterize FTTH co-investment: 'coinv' is a dummy variable for FTTH co-investment entry (0/1) in the municipality, and 'nbinv' represents the number of Orange's co-investors (0, 1, 2, 3). 'nbinv' is defined as the number of additional FTTH investors beyond the first investor (Orange). A 'coinv' dummy variable is also created, which assumes the value of one for all nonzero value of 'nbinv' and assumes the value of zero, otherwise. As expected, Table 7 shows that co-investment entry has a positive effect on FTTH coverage. Co-investment entry leads to an increase of 7.8% in FTTH coverage. More precisely, FTTH coverage is improved by 5% for each additional co-investor. These results are consistent with the results provided in Table 5. Since each additional co-investor contributes a 5% co-financing share in most cases, each additional co-investor increases FTTH coverage by $5 \times 0.8\% = 4\%$ (vs. 5% when using 'nbinv' in Table 7). In addition, the first-stage F-statistics remain well above the critical threshold of 10; Stock and Yogo's weak instrument test statistic and Sargan Hansen test are also above their critical thresholds. These outcomes support the validity of the dummy variable 'sfricable' or/and the ratio of competitors' mobile antennas as instruments for the alternative co-investment variables.

Table 7: Robustness check with alternative variables of interest: co-investment dummy and number of co-investors

VARIABLES	coverage	coverage
coinv	0.0777*** (0.011)	
nbinv		0.0500*** (0.007)
l4income	0.2480** (0.125)	0.2112 (0.131)
l4unemployment	-0.0338 (0.026)	-0.0306 (0.027)
l4edu	0.0294*** (0.008)	0.0293*** (0.008)
l4density	-0.0528*** (0.015)	-0.0574*** (0.016)
l3app	0.0392** (0.016)	0.0217 (0.018)
cable30	-0.0036 (0.005)	-0.0041 (0.006)
l4lineB	0.2432*** (0.091)	0.1939** (0.098)
y2014	0.0109 (0.015)	0.0063 (0.016)
year_dummy	Y	Y
year_dep	Y	Y
Observations	14,054	14,054
R-squared	0.348	0.303
Number of municipalities	3,573	3,573
First-Stage F-statistic	63.31	40.68
Standard errors appear in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$		

■ Difference-in-differences

We also checked for differences between the areas that received co-investment and those that did not by using the difference-in-differences approach. To do this, we constructed a 'treatment group' and 'control group' as follows:

- The 'treatment group' includes all 136 municipalities with co-investment in 2015. We create a dummy variable 'coinv2015' for this group ('coinv2015'=1). We include two annual observations for the 'treatment group' before treatment (2013–2014) and two annual observations after treatment (2015–2016).
- The 'control group' ('coinv2015'=0) includes 264 municipalities where FTTH deployment is operated by a single private operator without co-investment from 2013-2016. We also include two annual observations for 'control group' before treatment (2013–2014) and two annual observations after treatment (2015–2016).

First, we implemented the difference-in-differences method by simply computing the mean value of 'coverage' before and after co-investment entry for both the 'treatment group' and the 'control group'. Table 8 shows that the average FTTH coverage is respectively 6% and 1% for areas that received co-investment and those that did not before co-investment entry. After co-investment entry in 2015, FTTH coverage is 12% higher for the 'treatment group' (with co-investment) than for the 'control group' (without co-investment). Therefore, the difference in differences is 7%.

Table 8: Mean value of FTTH coverage before and after co-investment entry

	Co-investment areas	Non co-investment areas	Difference
Before co-investment	6%	1%	5%
After co-investment	14%	2%	12%
Change	8%	1%	7%

Then, we considered the following difference-in-differences model:

$$Y_{it} = \gamma \text{coinv2015} + \lambda \text{time} + \delta \text{coinv2015} * \text{time} + \beta X_{it} + \varepsilon_{it} \quad (3)$$

Table 9 shows that the interacted variable 'DiD'=coinv2015*time has a positive coefficient. This positive coefficient can be interpreted as a positive treatment effect of the co-investment entry indicated by δ . This result is also consistent with the results presented in Table 7.

Table 9: Difference-in-differences regression

VARIABLES	coverage	
DiD	0.0696*** (0.012)	0.0722*** (0.011)
coinv2015	0.0487*** (0.005)	0.0604*** (0.006)
time	0.0103*** (0.003)	0.0075** (0.004)
l4income		3.1939*** (0.556)
l4unemployment		-0.1046 (0.069)
l4edu		-0.0573** (0.026)
l4density		0.0052*** (0.002)
l3app		-0.0598*** (0.012)
cable30		-0.0287*** (0.006)
l4lineB		0.1016 (0.211)
Constant	0.0067*** (0.001)	-0.0109 (0.019)
Observations	1,600	1,564
R-squared	0.232	0.350

Standard errors appear in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

7 Impact of FTTH co-investment on FTTH adoption and on fixed broadband market competition

Until now, we have only estimated the impact of co-investment on FTTH coverage. The FTTH adoption rate is determinedly conditioned by FTTH coverage. On the other hand, 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 and also on fixed broadband market competition. Since the co-investors' customers' FTTH adoption is not observed, we

develop a simple model to estimate Orange’s customers’ FTTH adoption and fixed broadband market competition based solely on data obtained from Orange. The data include the number of Orange’s customers subscribing to ADSL and FTTH. The addition of $P_{af} = P_a + P_f$ provides the total number of Orange’s fixed broadband customers. As the fixed broadband market is not yet fully saturated, $P_{af} = \alpha_t * t$ is still increasing over time with $\alpha_t > 0$. This increase may be impacted by the co-investment of Orange’s competitors, which is represented by the co-financing share s_t , $P_{af} = \alpha_t * t - \kappa * s_t$. The term $\kappa * s_t$ corresponds to the share of customers who leave Orange and adopt its competitors’ FTTH.

To determine the impact of competitors’ co-investment on Orange’s customers’ FTTH adoption and on Orange’s total fixed broadband penetration P_{af} , defined as the ratio of Orange’s total number of fixed broadband customers (ADSL and FTTH) to the number of houses in the municipality, we estimate the following equation:

$$P_{af}(P_f) = \kappa_c * s_{it} + \beta_c X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (4)$$

In this specification, the endogenous variable for the co-financing share s_{it} is always instrumented by ‘sfricable’ or/and the difference in the number of competitors’ mobile antennas and those owned by Orange in the municipality. In practice, the equation 4 becomes the same as equation 2 by replacing the dependent variable with P_f or P_{af} . As expected, the outcome using ‘adoption’ is similar to that when using ‘coverage’ because FTTH adoption is required for FTTH coverage. We find that a 1% co-financing share by co-investors increases Orange’s FTTH adoption by 1.2% (cf. the second column in Table 10) and decreases Orange’s fixed broadband (ADSL and FTTH) penetration P_{af} by 1.1% (cf. the last column in Table 10), which leads to increased competition. This additional result shows that co-investment is not only beneficial for coverage but also increases the positive effects of FTTH adoption and competition.

Table 10: Impact of co-investment on FTTH adoption and fixed broadband competition

VARIABLES	Pf (FTTH adoption)	Paf
cofinancing	1.2058*** (0.163)	-1.1258** (0.498)
l4income	0.3492** (0.176)	0.3316 (0.214)
l4unemployment	-0.0737** (0.035)	0.0723 (0.048)
l4edu	0.0294*** (0.011)	-0.0002 (0.016)
l4density	-0.0700*** (0.021)	-0.0817*** (0.024)
l3app	-0.0305 (0.023)	0.0430 (0.035)
cable30	-0.0061 (0.007)	-0.0067 (0.009)
l4lineB	0.1401 (0.130)	0.2588* (0.144)
year dummy	Y	Y
year_dep	Y	Y
Observations	14,054	14,050
R-squared	-0.002	-0.490
Number of municipalities	3,573	3,573
First-Stage F-statistic	45.75	11.96
Standard errors appear in parentheses:	*** $p < 0.01$,	** $p < 0.05$, * $p < 0.1$

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. We utilized several French municipality-level datasets that provide data for the period 2013-2016. During this period, co-investment in FTTH deployment was introduced in less dense municipalities (ZMD and

AMII) and has rapidly developed. Our estimates show that for each 1% of co-financing by Orange's co-investors, FTTH coverage increased by 0.8% on average and annual progression by 0.6%. These findings are robust to changes in the model specifications and the use of different instruments. Using a simple difference-in-differences estimation for FTTH covered areas as a benchmark shows that the co-investment schema increases FTTH coverage in co-investment areas more than in non co-investment areas.

In addition, a 1% co-investment share increases FTTH adoption (measured by the number of Orange's fixed broadband customers) by 1.2% and decreases Orange's fixed broadband (ADSL plus FTTH) penetration by 1.1%, which leads to increased competition. Our findings show that the FTTH co-investment regime leads to faster coverage, higher adoption and more intense 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.

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