Entry Into Fiber and State Aid for the Deployment of High-Speed Internet: Evidence from France*

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July 5, 2022

Abstract

This paper evaluates the impact of State aid granted to local authorities in France through the French broadband scheme *Plan France Très Haut Débit*. We exploit a rich dataset containing information about fiber deployment, State aid, and socio-demographic characteristics of more than 34,000 municipalities in Mainland France over 2014-2019. First, we study the determinants of entry into fiber and evaluate the plan's efficiency using a structural model of entry. Second, we assess the impact of State aid on broadband coverage. We find that the plan was relatively efficient in solving a market failure – low coverage in low-density areas – but at the cost of some crowding out. The plan also helped increase fiber coverage in aided municipalities at the early stages of fiber deployment.

Keywords: High-Speed Broadband; State Aid; Market Entry.

JEL Classification: K23, L13, L51, L96.

*This paper was written as part of the State aid *ex-post* evaluation program undertaken by *France Stratégie*, from which we acknowledge financial support. We thank Zichuan Li for his research assistance and participants to the 2021 Digital Economics Summer School organized by the Association Francophone de Recherche en Economie Numérique (AFREN) and to the 2021 Doctoral Workshop on the Economics of Digitization at Telecom Paris for helpful comments. All errors are our own.

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1 Introduction

Since the launch of the Digital Agenda for Europe in 2010,[1] the European Union (EU) has set goals for nationwide broadband coverage as well as wide coverage with next-generation access (NGA) networks. Such networks are considered of strategic importance for the consolidation of a digital single EU market, fostering economic and social development, and closing the digital and economic divide in rural areas.[2]

Member States from the European Union can provide support for the deployment of broadband networks, subject to some conditions. In particular, financial support must comply with EU State aid rules.[3] Public subsidies are allowed in places where a market failure exists; private operators have no incentive to deploy on their own, yet investment may bring significant improvements to local markets.

In this context, in 2013, France notified to the European Commission the *Plan France Très Haut Débit* (hereafter the "French Broadband Plan"), a national plan for high-speed broadband,[4] aiming to provide broadband connections of at least 30 Mbps for all by the end of 2022 and fiber connections for all by 2025. This Plan represents a total budget of 3 billion euros.

In this paper, we study the efficiency and the impact on fiber coverage of State aid granted to local authorities through this Plan. First, we study the determinants of entry into fiber and evaluate the efficiency of the plan. We understand efficiency here as the ability of the plan to grant aid only to municipalities where entry would not occur otherwise. Second, we assess the impact of State aid on fiber deployment, controlling for the endogeneity of fiber entry.

We use panel data over the period 2014-2019 containing information about fiber deployment, number of infrastructure operators, State aid and socio-demographic characteristics of more than 34,000 municipalities in Mainland France.[5] We adopt a two-step empirical approach. In the first step, we build a model of fiber entry by infrastructure operators in local municipalities. We find that local market characteristics, such as the size of the market and income, are important

[1]See 'A digital agenda for Europe,' COM(2010)245 final, Brussels, 19 May 2010.

[2]High-speed broadband infrastructures are expected to stimulate growth and job creation through increased productivity and by stimulating innovation in products and services. See Röller and Waverman (2001), Czernich, Falck, Kretschmer and Woessmann (2011) and Ahlfeldt, Koutroumpis and Valletti (2017), among others, for empirical evidence on the positive impact of telecommunications infrastructures, and in particular broadband infrastructures, on growth and job creations.

[3]See: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2013:025:0001:0026:EN:PDF

[4]See: https://agence-cohesion-territoires.gouv.fr/france-tres-haut-debit-53; https://www.arcep.fr/demarches-et-services/collectivites/le-plan-france-tres-haut-debit-pfthd.html

[5]Our analysis does not include Corsica and overseas territories of France.

determinants of fiber entry. We also find a strong geographic dependence in fiber entry and evidence of a replacement effect from the legacy copper network in fiber entry decisions. Prior investment in neighbouring municipalities is a very strong determinant of investment, which suggests that cost factors play a more important role than demand factors in driving deployment decisions. Finally, we find that entry becomes easier over time.

Based on the estimates of the entry model, we compute "entry thresholds", that is, the minimum market size required to support fiber entry in a given municipality at a particular point in time. We use these entry thresholds to evaluate the efficiency of the French Broadband Plan. If a municipality benefiting from State aid has a market size lower than the entry threshold in a given period, we consider that the Plan was efficient in fixing a market failure. Otherwise, we consider that the Plan has crowded out potential private investment.

We find that the Plan was relatively efficient. In 93% of cases, State aid benefited municipalities where private entry would not have occurred during the year when State aid became effective. However, in its *State Aid Broadband Guidelines*, the European Commission considers that an area is eligible for State aid if there is prospect of private investment within three years.[6] Therefore, we also consider the possibility of entry of private operators during 3 years after State aid was granted. In this case, the degree of efficiency of the State aid plan falls to 64%. Thus, crowding-out of private investment cannot be ruled-out. It may result from the high levels of uncertainty about costs or demand for high-speed broadband at the early stages of fiber deployments.[7] We use our estimates to compute the cost of 'efficient' and 'inefficient' State aid in our two cases based on the average cost of State aid per line in a municipality. According to our estimates in 2019 in the 'myopic' scenario 'efficient' State aid corresponds to 1,960 million Euros and 'inefficient' to 243 million Euros. In the '3 years' scenario the respective numbers are 1,301 and 902 million Euros. These numbers represent upper bound because we use total number of lines in municipalities in the calculation which may be higher than the number of lines which received State aid. We also analyze which infrastructure operators invest predominantly in municipalities with State aid identified as inefficient and rely on State aid. We identify a few problematic cases.

In the second step of our empirical approach, we analyze how State aid affects fiber deploy-

[6]See "EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks," 2013/C 25/01), 26 January 2013, Article (75).

[7]The latter number is overstated because in the last years 2017-2019 we consider that the time horizon for entry is shorter than 3 years.

ment and coverage. We use a two-stage Heckman selection model to account for the endogeneity of fiber entry. We find that the French Broadband Plan allowed higher fiber coverage rates in aided municipalities compared to non-aided municipalities, especially at the beginning of the period of analysis. This effect decreases over time.

Thus, our results suggest that the French Broadband Plan has been relatively successful in helping to achieve the broad objectives of ultra-fast broadband deployment set by the EU, while limiting possible distortions in local markets. In addition, broadband deployment within the Plan could have generated spillovers and facilitate investment in neighbouring areas, as suggested by our findings.

The remainder of the paper is organized as follows. In Section 2, we review the relevant literature and discuss our contribution. In Section 3, we remind the objectives of the Digital Agenda for Europe, provide an overview of the EU State aid scheme, and describe the main features of the French Broadband Plan. In Section 4 we present our data sets. In Section 5, we introduce the econometric framework, and in Section 6 we discuss the estimation results. Section 7 concludes.

2 Literature Review

This paper contributes to three streams of the empirical literature on (i) entry in telecommunications markets, (ii) investment in next-generation broadband networks, and (iii) the impact of State aid on the deployment of broadband networks.

First, the paper relates to the literature on entry into local telecommunications markets. Using a latent variable representation of a market's profitability, this literature investigates the market characteristics influencing entry. In addition to the demand and cost shifters influencing entry (e.g., market size and population density), the literature highlights the role of differentiation (Greenstein and Mazzeo, 2006), sunk costs (Xiao and Orazem, 2011), managers' strategic ability (Goldfarb and Xiao, 2011), and entry threats (Wilson, Xiao and Orazem, 2021).

Nardotto, Valletti and Verboven (2015) use an entry model as a first stage to study the effect of entry of alternative operators on broadband penetration in the UK in 2005-2009. They find that entry did not foster broadband adoption but increased the quality of service to the benefit of consumers. Bourreau, Grzybowski and Hasbi (2019) use a similar approach to study the impact of competition on the legacy copper network on the deployment of high-speed broadband in France.

They find that a higher number of local competitors in a municipality reduces the incentives to deploy and expand broadband coverage with speed of 30Mbps or more. We contribute to this literature by investigating the role of State aid on entry into local telecommunications markets. We also consider fiber entry in local markets where legacy broadband (ADSL) services are already available, taking into account the competition between the "old" broadband technology and the "new" fiber technology.

Second, this paper contributes to the empirical literature on investment in next-generation access (NGA) fiber networks. This literature focuses on the impact of sectoral regulation on the deployment of fiber networks (see, e.g., Bacache, Bourreau and Gaudin (2014), Briglauer (2015), and Briglauer, Cambini and Grajek (2018)). In particular, Briglauer et al. (2018) use data on incumbent telecommunications operators and cable operators for 27 European member states for the period 2004-2014, and show that more stringent access regulation harms investment by incumbent telecommunications operators. In a similar vein, Fabritz and Falck (2013) find that deregulation stimulated the roll-out of fiber by the incumbent telecommunications operators in the UK in 2007-2013. Briglauer, Cambini, Gugler and Stocker (2021) study the impact of net neutrality regulations on fiber and cable infrastructure investment and subscriptions. Using data on 32 OECD countries for 2003-2019, they find that these regulations have reduced investment and subscriptions. The present paper contributes to this stream of literature by considering another form of public intervention, State aid. We then analyze the impact of State aid on the deployment of NGA fiber networks.

Finally, our paper is related to the literature on the impact of State aid on the deployment of broadband networks. This literature focuses mainly on case studies of European Union member states. Matteucci (2019) discusses the effect of the Italian State aid plan for deploying the first generation of broadband. He argues that State aid allowed to expand broadband coverage in rural areas, but with a delay compared to other areas. Briglauer et al. (2019) assess the impact of a State aid program introduced by the German State of Bavaria in 2010 and 2011 to improve broadband availability in rural areas. The authors find that aided municipalities have higher broadband coverage at a higher speed than non-aided municipalities.

Duso et al. (2021) study the impact of State aid broadband plans implemented in Germany between 2011 and 2013 on broadband availability and competition. They find that State aid has improved broadband coverage in the targeted areas without distorting local competition. Briglauer and Grajek (2021) use cross-country data to study the effectiveness of State aid programs for the deployment of new fiber broadband networks. Using data from 32 OECD countries for 2002-2019, they find that State aid significantly increased broadband coverage. Finally, Wilson (2021) studies the impact of public investment in broadband infrastructure on private investment using nationwide U.S. data. He estimates the demand for internet access and a dynamic oligopoly model where private and public firms make entry and investment decisions. He finds that public investment crowds out private investment to some extent. However, this effect is dominated by a dynamic preemption effect, whereby the threat of public provision of broadband induces private firms to invest preemptively.

We contribute to this strand of literature by studying the efficiency of State aid for the deployment of fiber networks in France using micro-level data.

3 State Aid for Broadband and the French Broadband Plan

3.1 EU Digital Agenda and State Aid for Broadband

In May 2010, the European Union (EU) announced its Digital Agenda to boost Europe's economy and consolidate the EU Digital Single Market. At the time, Europe was lagging behind other regions in terms of fast and reliable digital networks.[8] Moreover, coverage with very-high capacity fiber networks capable of delivering ultra-fast broadband[9] was much smaller in rural areas than in urban areas, revealing a persistent digital divide.[10]

Several factors can explain the slow transition from basic to ultra-fast broadband. First, on the supply side, the roll-out of very-high capacity networks requires large fixed and sunk costs. Operators may also face an opportunity cost when deploying next-generation networks due to their revenues from the legacy copper network (the so-called "replacement effect"). Finally, operators deploying fiber face competition from Internet service providers using other technologies (e.g., DSL and cable). On the demand side, switching costs may refrain basic broadband users from subscribing to new ultra-fast broadband offers. Moreover, their willingness to pay for higher

[8]See: European Commission, "The EU explained: Digital Agenda for Europe," November 2014.

[9]Very-high capacity networks (VHCN) correspond to "any network providing a fixed-line connection with fiber roll out at least up to the multi-dwelling building" or any network providing the same quality of service (BEREC, 2020). Ultra-fast broadband, allowing connection speeds of 100Mbps or more, requires VHCNs.

[10]In 2011, 10% of households were covered with very-high capacity networks in the EU but only 2% in rural areas. See: European Commission, "Digital Economy and Society Index (DESI)," 2020, p. 10-11.

speeds might be low, at least at the early stages of the diffusion of the new technology.

Most importantly, in rural and less densely populated areas, there may be a market failure for the provision of ultra-fast broadband. While deployment costs are higher than in dense urban areas, the potential demand might be low and/or uncertain. Thus, private operators may have no incentive to deploy ultra-fast broadband networks in these areas. However, it may be socially desirable to cover these areas due to high economic and social benefits not internalized by market players.

As demand for fast and reliable connectivity increases and the digital divide becomes visible, the need for widespread deployment of very-high capacity networks has become a primary objective. The 2010 Digital Agenda for Europe defined the objective of providing at least 50% of European households with access to ultra-fast broadband by 2020. In 2016, the EU updated its target, with the objective that by 2025, all EU households have access to ultra-fast broadband.[11]

To foster the deployment of very-high capacity networks, the European Commission issued recommendations on next-generation access networks and revised its State aid guidelines for broadband deployments. State aid is an important policy tool for the deployment of networks in rural and low-density areas, where it is not financially viable for private operators to deploy on their own.[12]

State aid control is intended to ensure that the positive effects of the aid outweigh possible distortions of competition. For broadband specifically, State aid schemes must achieve a higher level of coverage and penetration in areas where a market failure exists. State aid should also not be granted in areas where market operators have already invested or would normally choose to invest. Otherwise, they would crowd out private investment and distort competition.

3.2 The French Broadband Plan

In 2013, the French government launched the *Plan France Très Haut Débit* (hereafter, the "French Broadband Plan"). This plan supports the design and funding of broadband infrastructure in France, mainly based on fiber-to-the-home (FTTH) networks.

Under this program, the French territory is divided into private and public initiative zones.

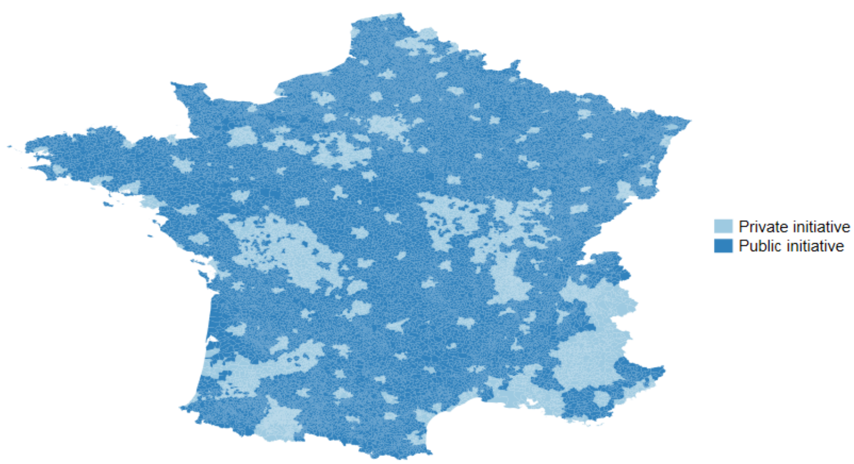
[11] See: European Commission, "Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society," COM(2016) 587 final.

[12] Article 107(1) of the Treaty on the Functioning of the European Union (TFEU) defines State aid as "any State resources granted by a Member State which distorts or threatens to distort competition by favoring certain undertakings or the production of certain goods."

Private initiative zones are areas where fiber deployment does not require public funding. In very densely populated areas, the deployment of fiber networks is expected to be driven by infrastructure-based competition.[13] In some less densely populated areas, major telecommunications operators have also expressed their intention to deploy very-high capacity networks without public support.

Public initiative zones are areas (typically rural) where no private investment is planned for the deployment of fiber networks. With the support of the State and the EU, local authorities can cover these areas by forming partnerships with private operators. Access to the subsidized network must be open and non-discriminatory, with oversight by the French regulator, ARCEP.

Figure 1: Public and private initiative zones for fiber coverage in France as of the fourth quarter of 2020.



Source: own elaboration based on data from AVICCA.
Note: 27,566 municipalities are categorized as public initiative zones and 6,792 as private initiative zones. 85 municipalities are mixed initiative zones (they have both private and public initiative networks). They are depicted here as part of the private initiative zone.

Figure 1 shows the distribution of private and public initiative zones in the fourth quarter of 2020. Public authorities estimated that a total investment of 21 billion euros over 10 years,

[13]Very dense areas were defined by ARCEP in 2009 as a list of 148 municipalities. In 2013, ARCEP revised the list, reducing the number of municipalities to 106 due to the absence of deployment or infrastructure-based competition in some municipalities.

from both public and private sources, would be necessary to achieve the objectives set by the French Broadband Plan.[14] Within this total investment, the program consolidates a State budget of around 3 billion euros to support the deployment of public initiative networks (*"Réseaux d'initiative publique"* or "RIP" by its French acronym). Eligibility for State funding is subject to examination by the ANCT (*"Agence Nationale de la Cohésion des Territoires"*, previously *"Agence du Numérique"*).[15] State subsidies are paid in several installments, spread over several years, at the rate of the construction of the network and after proof that the network has been built in accordance with current regulations and technical specifications. Projects are designed at the department or supra-department level, and applications are under the responsibility of local authorities.[16]

In 2016, the European Commission approved the French Broadband Plan. As of January 2021, 82 projects were eligible to State aid (74 in Mainland France). Table A.1 in the Appendix presents the list of projects with the departments or regions concerned.

4 Data

We combine several data sources. First, we use data on fiber-to-the-home (FTTH) infrastructure provided by ARCEP. Second, we build a database on State aid at the municipality level using information from the ANCT. Third, we collect information on socio-economic and geographic characteristics of municipalities from INSEE (French National Institute for Statistics and Economic Studies). Fourth, we use information from AVICCA (French association dedicated to local authorities involved in electronic communications and audiovisual) to identify the type of zone of each municipality (public, private or mixed). Fifth, we use information on the quality of the French copper network provided by the incumbent operator Orange.

Data on FTTH infrastructure. We received data from ARCEP on the geographic location, deployment status, and the identity of the fiber infrastructure operator for more than 16 million

[14]See: France Stratégie (2020), "Déploiement du très haut débit et Plan France très haut débit. Evaluation socioéconomique", Technical report.

[15]State aid concerns only certain parts of the network, namely passive elements of the network, civil engineering works, reception equipment for satellite technologies and terrestrial wireless networks - exceptionally and in a limited manner – and studies directly related to the project.

[16]Local authorities are French administrative structures, distinct from the State administration, which are in charge of the interests of the population of a specific territory (municipalities, departments, regions, etc.). Local authorities can join forces to exercise their powers by creating public cooperation bodies.

buildings in France as of June 2020. We aggregate this data at the municipality level using the geographic location of each building. The data contains information about the date of availability of the mutualization point (MP) of each building. We adopt this date as the date of fiber entry, as it indicates that the costliest part of the fiber network has been deployed.[17]

For each quarter between 2014-2019, we thus observe the number of fiber operators and the number of FTTH lines deployed in each municipality of Mainland France. To estimate the fiber coverage rate in each municipality, we use publicly available data from ARCEP on the total number of dwellings (hereafter "lines") in each municipality in 2020.[18] We define the fiber coverage rate as the ratio between the number of fiber lines deployed and the total number of lines (dwellings) in the municipality.

Figure 2 shows the evolution of FTTH deployment in France in public, private and mixed initiative zones. By the end of 2019, more than 60% of French households were covered with fiber (i.e., the mutualization point of the building was available). However, while coverage is slightly above 80% in private and mixed initiative zones, it is less than 30% in public initiative zones.

Panels (a) and (b) of Figure 3 show the geographic location of fiber deployments in the first period (2014Q1) and the last period (2019Q4) covered by our data. The first deployments occurred in the main urban areas, and then tend to expand as clusters around the municipalities initially covered. To account for any geographic dependence in fiber deployments and potential spillover effects, for each municipality we calculate the average fiber coverage in neighboring municipalities in the previous quarter.[19]

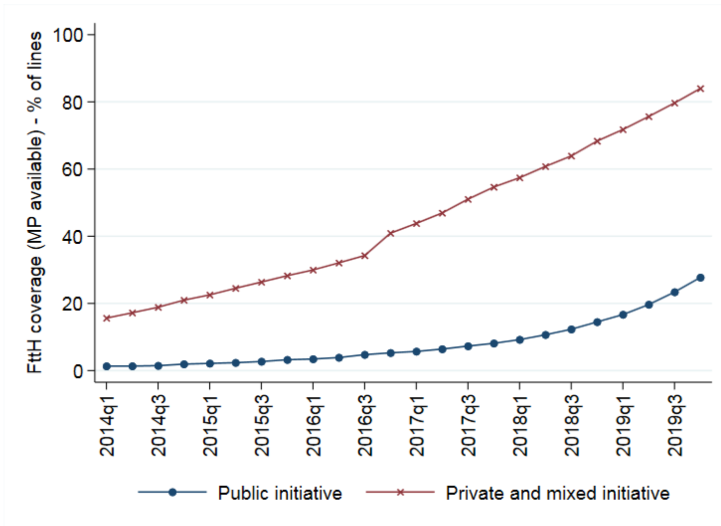
Table 1 presents the number of municipalities with different numbers of infrastructure operators for the period 2014-2019. Only a few municipalities have two or more infrastructure operators. Moreover, Table A.3 in the appendix shows that there is a large number of entries and no exits by fiber infrastructure operators in Mainland France during this period.

[17]For some buildings, the MP availability date is missing. In this case, we replace the missing information by the availability date of the first optical connection point (*Point de branchement optique* in French) deployed in the building.

[18]ARCEP's data was retrieved on 20 May 2021 from the following website: https://www.data.gouv.fr/en/datasets/ma-connexion-internet/. We compare this information with the number of lines provided by AVICCA. For a few municipalities, the total number of lines according to ARCEP is different than the one provided by AVICCA. We keep the source that yields the number of lines closer to the number of households in the municipality reported by INSEE. In a few cases, the number of lines deployed is greater than the total number of lines in the municipality; we then set the former equal to the latter.

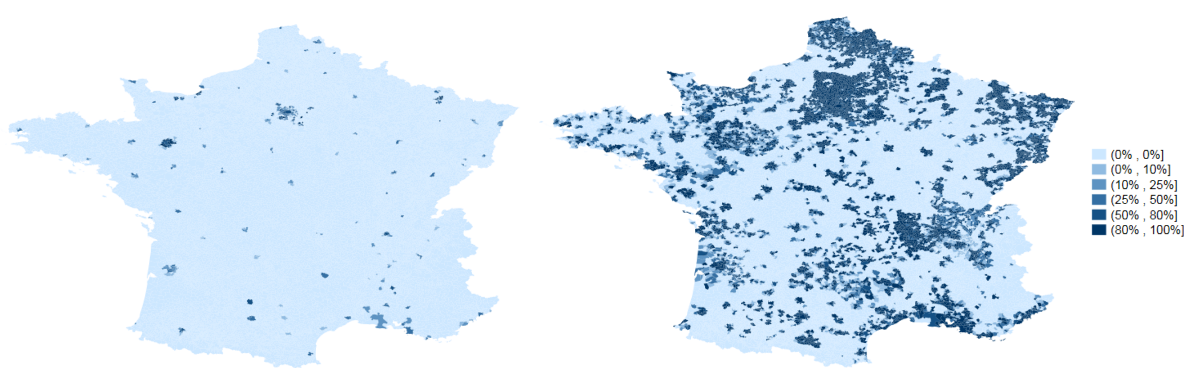
[19]Neighboring municipalities are those that have a boundary with a given municipality. The list of neighboring municipalities as of January 2021 in Mainland France was retrieved on 22 June 2021 from the following website: www.data.gouv.fr/en/datasets/liste-des-adjacences-des-communes-françaises.

Figure 2: Evolution of fiber deployment in France.



Source: ARCEP.

Figure 3: Fiber coverage in Mainland France municipalities (rate of connectable lines - 2014Q1 and 2019Q4).



(a) 2014Q1 (b) 2019Q4

Data on State aid. We received two data sets from the ANCT on State aid in the context of the French Broadband Plan. The first data set includes information about the decisions made

Table 1: Number of municipalities with presence of infrastructure operators.

	Number of infrastructure operators					
Year	0	1	2	3	4	5
2014	33 827	495	73	37	10	1
2015	33 404	905	77	41	15	1
2016	32 271	1 983	112	60	16	1
2017	30 838	3 301	191	89	22	2
2018	27 905	6 054	326	132	24	2
2019	22 840	10 875	522	169	34	3

by the Prime Minister on projects presented by local authorities requesting State aid.[20] For each project, we have information about: (i) the departments concerned; (ii) the type of decision (preliminary agreement, final decision, other); (iii) the date of the decision; (iv) the reference number of the decision; (v) the amount of aid granted; and (vi) a dummy variable indicating whether the decision was valid as of January 2021. Second, for each project we obtained a "proxy" file used by the ANCT to calculate the amount of the aid. Each proxy file contains an approximation of the number of lines eligible to State aid in each municipality.

We combine these two data sets to construct a database identifying the municipalities in Mainland France benefiting from State aid. Local authorities receive State aid as reimbursements when they present proof of network construction. For our analysis, we make the simplifying assumption that State aid is effective when the first FTTH line is deployed in the municipality.[21]

As of January 2021, there are 74 projects in Mainland France with a valid State aid decision (either preliminary or final). They represent a total amount of State aid of 2.82 billion euros. We focus on the State aid projects confirmed by the Prime Minister through final decisions, which corresponds to an amount of aid of 2.58 billion euros.[22] Figure 4 shows how the 2.58 billion euros of State aid are divided by year of final decision.

Table 2 presents the cumulative number of municipalities benefiting from State aid in Mainland France during the period 2014-2019. By the end of 2019, 6,771 municipalities had benefited from State aid.

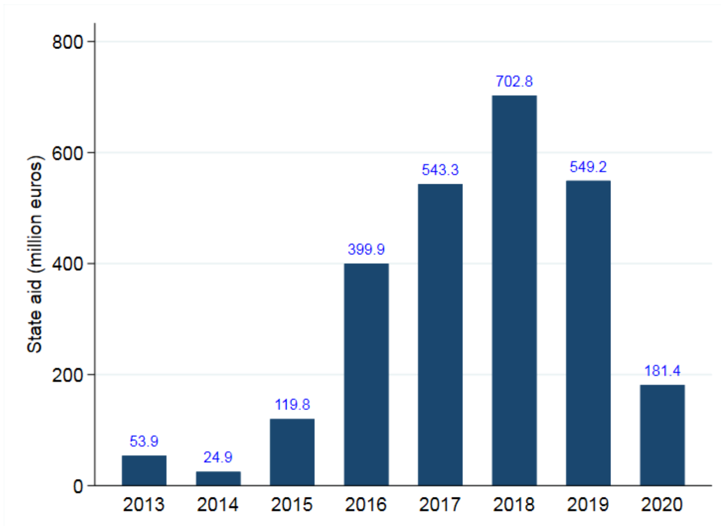
[20]Projects are conceived at the department or supra-department level.

[21]On average, we observe the first deployment in an aided municipality four quarters (one year) after the date of the aid granting decision by the Prime Minister.

[22]Preliminary decisions can be subject to changes throughout the scrutiny process by the ANCT and may not give way to disbursements.

Figure 6 in the appendix shows the geographic location of aided municipalities.

Figure 4: State aid by year of the final decision by the Prime Minister.



Source: ANCT.
Only final decisions for Mainland France are considered

Table 2: Cumulative number of municipalities with State aid.

Year	Total
2014	23
2015	191
2016	560
2017	1,451
2018	3,564
2019	6,771

Data on socio-economic characteristics of municipalities. We obtained socio-economic information at the municipality level from the French National Institute for Statistics and Economic Studies (INSEE). In particular, we have municipal-level data on the population size (defined as the number of households). This information is published with a two-year delay and is available only until 2017. Since firms do not have access to more recent statistics, we consider that they make their entry decisions based on demographic information with a two-year lag. In addition, we have information on the median household income per municipality in the years 2014-2017.[23]

Data on zone types. We retrieved data on the type of zone of each municipality in Mainland France from AVICCA.[24] Using this information, we are able to identify whether a municipality belongs to a public, private or mixed initiative zone in the context of fiber deployment. By the end of 2020, 80% of municipalities in Mainland France (40% of population) were categorized as public initiative zones.

Data on the quality of the copper network. Information on the quality of the legacy copper network in each municipality was obtained from the French incumbent operator Orange. We use this information to proxy for the opportunity cost incumbent operators may face when deploying next-generation networks due to their revenues from the legacy copper network (the so-called "replacement effect"). In general, broadband signals traveling along a copper line from an exchange point to a customer's location suffer attenuation. This is called copper loss and translates into a reduction of speed on DSL access. The further a customer is from the exchange, the more copper loss they can experience.

In our data, municipalities are assigned to the following categories based on the average quality of copper lines measured in decibels (dB): 20dB and below (outstanding); 20-30dB (excellent); 30-40dB (very good); 40-50dB (good); 50-60dB (poor and may experience connectivity issues); and 60dB or above (bad, will experience connectivity issues).

We merged the different data sets using the unique INSEE code for each municipality. After merging, we have information on 34,443 municipalities in Mainland France for the years 2014-2019, at a quarterly pace, resulting in a total of 826,632 observations.[25] Table 3 reports summary statistics for the variables used in the analysis.

[23]This information comes from the *Dispositif Fichier localisé social et fiscal (Filosofi)* and is missing for municipalities with less than 30 households. We replace missing values by the median household income in the department.

[24]The information corresponds to the fourth quarter of 2020, and was collected from the following website: www.avicca.org/content/open-data-avicca.

[25]There were 34,479 municipalities in Mainland France in the year 2020. Due to administrative changes in the years 2014-2019 (some municipalities split and others merged) and lack of information for some small municipalities in the different data sources, we removed from the data 36 small municipalities.

Table 3: Summary statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Number of infrastructure operators	826,632	0.11	0.36	0	5
Number of households (thousands)	826,632	0.76	3.37	1	100
Fiber coverage (%)	826,632	0.07	0.23	0	1
State aid (dummy)	826,632	0.04	0.21	0	1
Income (euros)	826,632	20,327	3,419	9,958	48,310
Public initiative zone (dummy)	826,632	0.80	0.40	0	1
Private initiative zone (dummy)	826,632	0.20	0.40	0	1
Mixed initiative zone (dummy)	826,632	0.00	0.05	0	1
Copper line quality - outstanding	826,632	0.18	0.39	0	1
Copper line quality - excellent (dummy)	826,632	0.16	0.37	0	1
Copper line quality - very good (dummy)	826,632	0.14	0.35	0	1
Copper line quality - good (dummy)	826,632	0.18	0.39	0	1
Copper line quality - poor (dummy)	826,632	0.16	0.37	0	1
Copper line quality - bad (dummy)	826,632	0.17	0.37	0	1

Note: The maximum values of number of households were truncated to 100,000 due to a few extreme cases. There are 34,443 municipalities and 24 quarters in our database.

5 Econometric Models

In this section, we present the econometric models. First, we set up a model of fiber entry, which allows us to estimate the determinants of the fiber entry decision. Next, using the estimates from on the entry model we calculate entry thresholds, which we use to assess the efficiency of the French Broadband Plan. Finally, we introduce a reduced-form model of fiber coverage, in which we take into account the endogeneity of fiber entry through a control function approach.

5.1 Fiber Entry

We set up a model of entry similar to the one used by Bourreau et al. (2019) to study the demand-side and supply-side factors that influence LLU entry in France. However, our focus is on the analysis of fiber entry by infrastructure operators. We assume that at the end of each time period, operators decide whether to enter into "new" local markets and deploy fiber network to the homes in the next period. They form expectations about market demand, costs and competition with other operators. These expectations are fulfilled in equilibrium, and the marginal operator enters the market. We draw inferences on the profit determinants assuming a free entry equilibrium, where operators enter a local market if, and only if, it is profitable for them to do so, i.e., expected gross profits outweigh the entry costs. As mentioned earlier, we do not observe exits in our data, and thus entry is a final decision.[26]

The number of fiber entrants in municipality i at time t is denoted as $N_{it} = n \in \{0, 1, 2, 3, 4, 5\}$. The discounted future stream of profits of an operator facing n competitors in market i at time t can be written as:

$$\bar{\pi}_{it}^{n} = \alpha S_{it} + \sum_{b_k \in B} \alpha_{b_k} S_{it} \times \mathbb{1}\{S_{it} \in b_k\} + X_{it}\beta - \mu^{n} + \epsilon_{it} \equiv \pi_{it}^{n} + \epsilon_{it}, \tag{1}$$

where S_{it} is the market size approximated by the number of households. To allow for non-linear market size effects due to economies of scale in fiber deployment, we introduce differential effects by market size intervals that we call "bands". To do so, we define vector $B = \{b_1, b_2, b_3, b_4, b_5\}$ as a set of five household size bands, with $b_1 = [0, 2,000)$, $b_2 = [2,000, 5,000)$, $b_3 = [5,000, 10,000)$,

[26] Some of the fixed costs of entry into local markets may be sunk. The presence of sunk costs implies that less demand is needed for an incumbent to continue operations than to support a new entrant. Sunk costs cannot be identified in our setup, because we observe only one entry at most and no exit at all. Thus, we estimate the entry model without sunk costs.

$b_4 = [10,000, 20,000)$, and $b_5 = [20,000, \infty)$. Next, we denote by X_{it} the vector of other characteristics of municipalities, which are potential demand or supply determinants of profits (including income, the type of zone, the quality of the legacy copper network and the fiber coverage in neighboring municipalities). We also include a set of year dummy variables and department dummy variables to allow for firms' profits to differ across geographic locations due to other factors.[27] Finally, μ^n represents the negative effect on profits from the n^{th} firm, and ϵ_{it} is the error term which has a standard normal distribution. The profits, π_{it}^n, are not observed and represent a latent variable.

This reduced-form profit specification is similar to the models estimated by Xiao and Orazem (2011), Nardotto et al. (2015) and Bourreau et al. (2019), and does not distinguish between marginal and fixed costs, as in Bresnahan and Reiss (1991). Our model does not account for heterogeneity between firms, which might be present due to to differences in size, geographic presence and cost structure.

Since there is only a small number of markets with two or more infrastructure operators, as shown in Table 1, we truncate the number of entrants to one, which simplifies our entry model. In equilibrium, in market i and at time t, there is entry of at least one fiber network $N_{it} = 1+$ when the condition $\bar{\pi}_{it}^1 > 0$ is satisfied, which yields, using the profit specification (1):

$$\alpha S_{it} + \sum_{b_k \in B} \alpha_{b_k} S_{it} \times \mathbb{1}\{S_{it} \in b_k\} + X_{it}\beta - \mu^1 + \epsilon_{it} > 0.$$

The probability of observing $N_{it} = 1+$ entrants in market i at time t is thus given by:

$$Pr(N_{it} = 1+) = \Phi(\alpha S_{it} + \sum_{b_k \in B} \alpha_{b_k} S_{it} \times \mathbb{1}\{S_{it} \in b_k\} + X_{it}\beta - \mu^1), \quad (2)$$

where $\Phi(.)$ denotes the cumulative normal distribution function. The parameter vector $\theta = (\alpha, \alpha_{b_2}, \ldots, \alpha_{b_5}, \beta, \mu^1)$ is estimated by maximizing the following log-likelihood function:

$$\hat{\theta} = \arg\max \sum_{i=1}^{M} \sum_{t=1}^{T} [y_{it} \ln(Pr(N_{it} = 1 + |\theta)) + (1 - y_{it}) \ln(Pr(N_{it} = 0|\theta))], \quad (3)$$

where y_{it} takes value of 1 when $N_{it} = 1+$, and 0 otherwise.

[27] In 2021, there were 94 departments in Mainland France, excluding Corsica.

We define $\hat{S}_{it}$ to be the necessary number of households in municipality i at period t to support the total of $N_{it} = 1+$ fiber networks, which we compute using the estimates $\hat{\theta}$ as follows:

$$\hat{S}_{it} = \frac{\hat{\mu}^1 - X_{it}\hat{\beta}}{\alpha + \sum_{b_k \in B} \alpha_{b_k} \mathbb{1}\{S_{it} \in b_k\}}. \tag{4}$$

We use the "entry threshold" defined above to assess the efficiency of the French Broadband Plan.

5.2 Deployment of Fiber

To analyze fiber deployment, we estimate a reduced-form equation for the share of households in a given municipality with access to ultra-fast broadband through fiber:

$$y_{it} = \rho SA_{it} + \gamma Z_{it} + u_{it}, \tag{5}$$

where y_{it} denotes the share of households in municipality i and period t with fiber coverage (i.e., the mutualization point is available in the household's building); SA_{it} is an indicator variable of State aid in municipality i and period t; and Z_{it} is a set of control variables that may determine coverage, including demand and cost shifters.

When estimating equation (5), we need to correct for a potential sample selection bias. That is, the fact that fiber coverage y_{it} is only observed when there is at least one infrastructure operator present in the municipality ($N_{it} = 1+$ in our entry model). To take this into account, we follow Heckman (1979) and estimate the model in two stages using a control function approach. More specifically, in the first stage we estimate the entry model discussed in the previous section (Model I). In the second stage, for the sample of municipalities with positive coverage, we estimate the following modified coverage equation:

$$y_{it} = \rho SA_{it} + \gamma Z_{it} + \sigma_{u\epsilon} \lambda(S_{it}, X_{it}; \hat{\theta}) + \varepsilon_{it}. \tag{6}$$

Assuming that the error terms of the these two models of fiber entry and fiber coverage, ϵ_{it} and u_{it}, are multivariate normally distributed, one can show that:

$$\begin{aligned} E(y_{it}|X_{it}, S_{it}, Z_{it}) &= \rho SA_{it} + \gamma Z_{it} + E(u_{it}|N_{it} > 0), \\ &= \rho SA_{it} + \gamma Z_{it} + \sigma_{u\epsilon} \lambda(S_{it}, X_{it}; \theta), \end{aligned} \tag{7}$$

where $\theta = (\alpha, \alpha_{b_2}, \ldots, \alpha_{b_5}, \beta, \mu^1)$ is the parameter vector from the entry model and $\sigma_{u\epsilon}$ is the covariance between u_{it} and ϵ_{it}. The hazard function (inverse Mills ratio) denoted by $\lambda(S_{it}, X_{it}; \theta)$ is defined using the entry model estimates as follows:

$$\lambda(S_{it}, X_{it}; \hat{\theta}) \equiv E(\epsilon_{it} | \hat{\pi}^n_{it} > -\epsilon_{it}) = \frac{\phi(\hat{\pi}^n_{it})}{\Phi(\hat{\pi}^n_{it})}. \tag{8}$$

Thus, in equation (6) we exploit the fact that the error term u_{it} can be decomposed into the sum of two terms and written as $u_{it} = \sigma_{u\epsilon}\lambda(S_{it}, X_{it}; \hat{\theta}) + \varepsilon_{it}$, where by construction ε_{it} is mean zero conditional on S_{it}, X_{it} and Z_{it}.

The municipality characteristics included in the estimation of equation (6) are the same as in the model of fiber entry, except for market size and the dummy variable identifying municipalities where there is no fiber coverage in neighboring municipalities in the previous period. These are our exclusion restrictions, which are required in the Heckman selection model.

In particular, we need at least one variable which determines entry of fiber operators but is not correlated with the error term in the coverage equation for fiber. Market size makes markets more attractive for deploying fiber but it should not affect the share of population covered by fiber. In other words, the share of population covered with fiber should be comparable in smaller and larger municipalities, conditional on the presence of infrastructure fiber operators in these municipalities. Moreover, the presence of fiber coverage in neighboring municipalities influences fiber entry as fiber backbones should allow to enter in several municipalities at the same time, but it may not have a direct impact on the level of coverage in the municipality. We expect that only the level of coverage in neighboring municipalities in the previous period may influence the current level of coverage in a given municipality. This is because coverage reflects how advanced are overall works on deployment in a specific area.

Although we do not expect a direct impact of market size on the deployment of fiber, it may be correlated with omitted municipality-specific characteristics. To mitigate this issue, we use in the estimation a set of municipality characteristics and department dummy variables, as well as year dummy variables. First, for comparison we estimate equation (6) using ordinary least squares (OLS) without correction term and then we use the Heckman's two-stage procedure described above.

6 Estimation Results

Our estimation is done in the following steps. First, we estimate the fiber entry model using the maximum likelihood estimator in equation (3). Second, we use the estimates from the entry model to compute entry thresholds, as described in equation (4). We use them to assess the efficiency of the French Broadband Plan. Third, we use the estimates from the entry model to compute the correction term (8). Fourth, we use ordinary least squares to estimate the coverage equation (6). This equation includes the number of fiber entrants and the correction term from the entry model (8). We also use local market characteristics and time and department dummy variables in the estimation as discussed above.

6.1 Fiber Entry

Table 4 shows the estimation results of our model of fiber entry using panel data for 34,406 municipalities over the period 2014-2019.[28] In practice, there are few municipalities with two or more infrastructure operators (e.g., only 2.1% of municipalities are in this case in the fourth quarter of 2019). Since there is almost no variation in the number of infrastructure operators, we focus on the presence of at least one infrastructure operator in the municipality. Our dependent variable is thus either 0 when no infrastructure operator is present in the municipality, or 1 when one or more infrastructure operators are present.

Some municipalities in which at least one infrastructure operator is present received State aid, but there are no aided municipalities where no infrastructure is deployed. Thus, State aid perfectly predicts entry. In order to identify the effect of State aid, we estimate three different models using alternative assumptions on municipalities benefiting from State aid. Model I is estimated using a restricted sample of 27,601 out of 34,406 municipalities that never received State aid during the period of analysis. This approach assumes that State aid is assigned randomly within the public initiative zone. This further implies that the likelihood of entry should be alike in aided municipalities, which by assumption have similar characteristics as non-aided municipalities. Model II is estimated by setting the number of infrastructure operators to zero whenever a municipality benefits from State aid. It assumes that entry would have not occurred

[28] Fiber entry occurred before the beginning of the period for all municipalities in departments Hauts-de-Seine and Paris. Since our model includes department dummies, they must be excluded from the analysis, which reduces the initial sample of 34,443 municipalities to 34,406 municipalities.

in aided municipalities in the absence of State aid. Finally, Model III is estimated using the full sample of municipalities. As State aid is not included as a control variable in this model, it assumes that entry would have occurred in municipalities benefiting from State aid, independently of State aid.

The results of the three models are qualitatively similar. We find that the market size (measured as the number of households in the municipality) significantly and positively affects fiber entry. The effect is non-linear and decreases with market size as suggested by the coefficients of the interactions between market size and market size bands. We also find that a higher level of income has a positive and statistically significant impact on fiber entry, indicating a higher demand for broadband in richer municipalities.

In the estimation, we also include two variables to test the intuition of a geographic dependence in fiber entry suggested by the graphical analysis of deployments (cf. Section 4). First, we use a dummy variable identifying municipalities where there is no fiber coverage in neighboring municipalities in the previous period. Its coefficient is negative and statistically significant, which indicates that the absence of fiber coverage in contiguous municipalities reduces the likelihood of entry. Second, we use a continuous variable on the average fiber coverage in neighboring municipalities in the previous period. It is positive and statistically significant, which implies that higher coverage in contiguous municipalities increases the likelihood of entry. We interpret this result as a confirmation of a geographic dependence in fiber entry and deployments. In practice, infrastructure operators have to roll out a fiber backbone, which is the nerve center of their fiber network. When a sufficiently high share of municipalities have been covered in a given area, the backbone has been deployed, which makes it less costly to cover additional contiguous municipalities.

The coefficients of year dummies are positive, statistically significant, and increase over time. This suggests that entry becomes easier over time, which may be due to technological progress and decreasing deployment costs. Demand for fiber may also be growing, with increasing needs for higher speeds and connection reliability. Unsurprisingly, entry is more likely in private and mixed initiative zones than in public initiative zones. Furthermore, municipalities with a lower quality of the legacy copper network experience more entry than municipalities with outstanding quality. This reflects the opportunity cost operators may face when deploying next-generation networks due to their revenues from the legacy copper network (the so-called “replacement effect”). Finally,

Table 4: Fiber entry in municipalities - presence of at least 1 infrastructure operator.

Dep. Var: Number of operators (0,1+)	(I)	(II)	(III)
Nb Households	0.511***	0.427***	0.523***
	(0.0684)	(0.0517)	(0.0577)
Ref: Nb Households interactions (< 2,000)			
Nb Households * [2,000 ; 5,000)	-0.155***	-0.124***	-0.183***
	(0.0439)	(0.0337)	(0.0371)
Nb Households * [5,000 , 10,000)	-0.268***	-0.215***	-0.281***
	(0.0589)	(0.0443)	(0.0488)
Nb Households * [10,000 ; 20,000)	-0.340***	-0.272***	-0.349***
	(0.0638)	(0.0483)	(0.0540)
Nb Households * (> 20,000]	-0.419***	-0.345***	-0.432***
	(0.0651)	(0.0497)	(0.0553)
Log(Income)	0.638***	0.520***	0.408***
	(0.177)	(0.138)	(0.144)
No coverage in neighbor dummy t-1	-0.870***	-0.989***	-0.821***
	(0.0414)	(0.0498)	(0.0377)
Level of coverage in neigbor t-1	3.260***	1.790***	3.263***
	(0.216)	(0.207)	(0.111)
Year dummies (ref 2014)			
2015	0.210***	0.255***	0.242***
	(0.0532)	(0.0481)	(0.0497)
2016	0.518***	0.579***	0.545***
	(0.0700)	(0.0741)	(0.0628)
2017	0.691***	0.711***	0.732***
	(0.0939)	(0.0913)	(0.0709)
2018	0.835***	0.860***	0.972***
	(0.120)	(0.138)	(0.0788)
2019	1.020***	0.832***	1.189***
	(0.172)	(0.155)	(0.0913)
Type of initiative zone (ref: public)			
Private initiative	0.921***	1.020***	0.184*
	(0.138)	(0.109)	(0.0968)
Mixed initiative	1.676***	1.574***	0.956***
	(0.466)	(0.356)	(0.367)
Copper loss (ref: <=20dB)			
20dB-30dB excellent	0.0904*	0.0631*	0.0975***
	(0.0473)	(0.0371)	(0.0355)
30dB-40dB very good	0.201***	0.136***	0.169***
	(0.0547)	(0.0431)	(0.0433)
40dB-50dB good	0.278***	0.224***	0.265***
	(0.0628)	(0.0442)	(0.0432)
50dB-60dB poor	0.343***	0.253***	0.336***
	(0.0535)	(0.0427)	(0.0422)
>=60dB bad	0.272***	0.213***	0.339***
	(0.0676)	(0.0593)	(0.0486)
μ_1	9.533***	8.349***	6.032***
	(1.830)	(1.448)	(1.474)
Department fixed effects	Yes	Yes	Yes
Observations	662,424	825,744	825,744
LL	-49921	-73325	-102454

Note: Robust standard errors in parentheses (clustered at the department level). Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively we include a set of department dummy variables in the estimation that are highly significant. They control for other factors determining the attractiveness of municipalities, which belong to the same department and do not vary over time.

In other unreported specifications of our model, we used surface area, employment rate, number of jobs, age categories, and active population by socio-professional categories as explanatory variables. None of them affect fiber entry significantly. In fact, they lose their significance when we use coverage in neighboring municipalities as a control variable in our model. We also tried estimating a model with random effects for municipalities, which, however, does not converge.

To sum up, our estimation results confirm the role of market size and other local market characteristics in determining fiber entry. In particular, our results suggest that fiber entry is driven by cost factors more than by demand factors, as deployment in neighboring areas seems to play an important role in entry decisions.

The three models we estimate may present different biases. In Model I, State aid might not be granted randomly. For example, there might be political factors or differences in the engagement of local representatives influencing the location and timing of State aid. In Model II, some aided municipalities could have experienced fiber entry in the absence of State aid. Finally, Model III makes the extreme assumption that fiber entry would have occurred in aided municipalities in any case, independently from State aid, which is not realistic.

Although State aid may not be assigned randomly within the public initiative zone, our preferred model is Model I, as it provides the best entry predictions among the three models (see Table A.2 for a comparison of prediction rates across models and years). Moreover, Models II and III make extreme assumptions about entry for municipalities benefiting from State aid. Model I makes correct predictions in 97% of cases. However, its prediction accuracy diminishes over time, in particular for the last two years (2018-2019) and for the cases of effective entry. This suggests that there are additional factors that we do not include in our model that may explain why entry accelerates at the end of the period. For instance, a strong increase of demand for ultra-fast broadband in recent years may have stimulated operators' deployment efforts. Non-economic reasons, such as the 'political will' of local authorities, may play a role as well.[29]

[29] For instance, in 2021, Brittany's local authority responsible for FTTH deployment signed an agreement with the consortium in charge of deploying the fiber network in the public initiative zones of the region. Its objective is to accelerate deployment after complaints by local inhabitants and mayors of delays in access to ultra-fast broadband. See: https://www.lesechos.fr/pme-regions/bretagne/les-retards-du-reseau-tres-haut-debit-breton-exaspere-entreprises-et-elus-1353384.

With these caveats in mind, we use the estimates from Model I to compute entry thresholds for each municipality, which we use to assess the efficiency of the French Broadband Plan.

6.2 Entry Thresholds and Efficiency of the French Broadband Plan

Based on the estimates of Model I in the previous section, we compute "entry thresholds", that is, the minimum market size required to support fiber entry in a municipality at a particular point in time. In Table 5, we define the market size as the number of households. We report average entry thresholds and market size for all municipalities in our sample and for the municipalities in which entry took place in a given year. The average number of households required to sustain fiber entry was initially close to 8,000, but it decreased to around 4,000 at the end of the period. Xiao and Orazem (2011) and Nardotto et al. (2015) also report entry thresholds for LLU that decrease over time. As they do, we consider that these falling entry thresholds may stem from declining investment costs, an increase in demand, or a combination of both. The decline in investment costs may be due to technology improvements or learning by doing in the construction of fiber networks.[30] Average entry thresholds in municipalities where entry occurred are in general lower than those of all municipalities, except in 2014. They are overall consistent with market size in order of magnitude.

Table 5: Average entry thresholds and market size.

	All municipalities		Municipalities with entry	
Year	Entry thresholds	Market size	Entry thresholds	Market size
2014	7970	718	9919	7566
2015	7436	718	6889	2179
2016	6647	718	6555	3034
2017	5950	749	5248	2286
2018	5191	749	4550	846
2019	4074	749	3535	714

Notes: Entry thresholds and market size are in terms of number of households.

To assess the efficiency of the French Broadband Plan, we compare the entry threshold

[30] Estimated entry thresholds for a few municipalities are negative. In particular, this is true for small municipalities with high fiber coverage in neighboring municipalities. We believe this is in line with decreased investment costs in areas where the fiber backbone is already deployed. Thus, for these cases, we consider that entry would occur almost independently from market characteristics, and set the entry threshold equal to one household.

predicted by Model I with the market size of each municipality. In principle, municipalities benefiting from State aid would present a market size lower than the entry threshold required for the market to be profitable for private operators. If this is indeed the case, we consider that the French Broadband Plan efficiently allocated State aid. Otherwise, the Plan may have allowed for early entry or introduced a market distortion by crowding out private investments.

Table 6 reports the following numbers: (i) the number of municipalities benefiting from State aid for the first time in each year; (ii) among them, those with entry thresholds higher than market size; and (iii) the proportion of aided municipalities for which we consider that the French Broadband Plan was efficient, resulting from the ratio between (ii) and (i). Table 7 shows the cumulative numbers over time. When considering contemporary entry predictions and State aid, our results suggest that the French Broadband Plan was rather efficient. Overall, in 93% of cases, the market size of municipalities benefiting from State aid was lower than the entry threshold predicted by our model in the year when State aid started to be effective. Thus, in these markets, entry by private operators was not expected in the given year.

However, as entry thresholds decrease over time, unaided entry by a private operator could have occurred in aided municipalities after the year when State aid took effect. Actually, the European Commission considers that an area is eligible for State aid if there is no NGA network at present in the area and it is unlikely that an NGA network can be built within three years.[31] Columns (iv) and (v) in Tables 6 and 7 show the same comparative analysis for the '3 years' case as for the 'myopic' case discussed above.

For 64% of the municipalities that benefited from State aid between 2014 and 2019, our model does not predict unaided entry by a private operator during the period of 3 years after the entry with State aid. However, for the remaining 36% of municipalities, private entry would have occurred over the period. Therefore, in these municipalities, public funding seems to have crowded out private investment, while accelerating fiber deployment compared to what the private sector would have achieved. The number for years 2017-2019 overstate State aid efficiency because we do not have predictions of entry thresholds for the entire period of 3 years after entry with State aid.

Thus, the French Broadband Plan contributed to fix a market failure by extending fiber coverage to areas that would not have been covered by private operators, but at the cost of some

[31] See "EU Guidelines for the application of State aid rules in relation to the rapid deployment of broadband networks," 2013/C 25/01), 26 January 2013.

Table 6: Efficiency analysis: Number and proportion of municipalities where State aid was necessary on a given year.

Year	(i) State aid	(ii) Entry threshold higher than market size: myopic	(iii) State aid efficiency	(iv) Entry threshold higher than market size: 3 years	(v) State aid efficiency
2014	23	23	100%	18	78%
2015	168	168	100%	149	89%
2016	369	365	99%	220	60%
2017	891	887	100%	544	61%
2018	2,113	1,918	91%	1,099	52%
2019	3,207	2,935	92%	2,309	72%
Total	6,771	6,296	93%	4,339	64%

Table 7: Efficiency analysis: Cumulative number and proportion of municipalities where State aid was necessary.

Year	(i) State aid	(ii) Entry threshold higher than market size: myopic	(iii) State aid efficiency	(iv) Entry threshold higher than market size: 3 years	(v) State aid efficiency
2014	23	23	100%	18	78%
2015	191	191	100%	167	87%
2016	560	556	99%	387	69%
2017	1,451	1,443	99%	931	64%
2018	3,564	3,361	94%	2,030	57%
2019	6,771	6,296	93%	4,339	64%

level of crowding out. It is important to notice that crowding out cannot probably be completely avoided, due to uncertainty about the demand for ultra-fast broadband or the level of investment costs, in particular in the early phases of fiber deployment. Besides, there is a delay between the date where the granting decisions is done and the moment where the actual deployment starts, which may reinforce this information problem.

Our model is estimated using data for years 2014-2019 and we assess the efficiency of State aid in the same period. But when making decision about State aid the regulator has information up to that point of time only. Thus, as a robustness check we estimate our model using data for years 2014-2016 only. We then apply the estimates to predict entry thresholds in years 2017-2019 and assess the efficiency of aided entry in this period. This is closer to evaluating the State aid decision process ex ante. Our results are comparable to those reported in Tables 6 and 7.

Next, we use our estimates to compute the cost of ‘efficient’ and ‘inefficient’ State aid in our two cases based on the maximum aid per line in a municipality.[32] These costs are the same for all municipalities in the same department but differ by department. The estimates are shown in Table 8. In this calculation we use the number of lines in each municipality which are reported by ARCEP and AVICCA and calculate cumulative cost over time for municipalities receiving State aid. The number of deployed lines which received aid is lower than total number of lines which we use in the calculation. Thus, our numbers represent the upper bound as being the maximum cost for the greatest number of lines in a municipality. According to our estimates in 2019 in the 'myopic' scenario 'efficient' State aid corresponds to 1,960 million Euros and 'inefficient' to 243 million Euros. In the '3 years' scenario the respective numbers are 1,301 and 902 million Euros.

Table 8: Cumulative cost of State aid for full coverage (mln Euros)

	Myopic				3 years			
	Efficient		Inefficient		Efficient		Inefficient	
	Cost	Lines	Cost	Lines	Cost	Lines	Cost	Lines
2014	23	46			17	34	6	12
2015	94	210			68	153	26	57
2016	264	602	33	65	106	239	191	427
2017	603	1,420	36	74	298	691	342	803
2018	1,074	2,681	103	305	579	1,398	598	1,588
2019	1,960	4,907	243	645	1,301	3,207	902	2,346

Note: The number of lines (in tsd) corresponds to total number of lines in municipalities reported by ARCEP and AVICCA.

We also analyze which infrastructure operators invest predominantly in municipalities with State aid identified as inefficient. In total there are 55 different infrastructure operators in our database. Among them we have identified an operator which invested in 213 municipalities among which 79% received State aid and 71% of these aided municipalities were identified as inefficient. There are also several operators which invested in municipalities among which more than 80% received State aid, but none of few cases were identified as inefficient.

6.3 Deployment of Fiber

Table 9 reports the estimation results for our coverage model. We estimate four regressions. We first consider a specification where the effect of State aid is constant (columns (1) and (2)).

[32]Source: "Investissements d'Avenir - Developpement de l'Economie Numerique. France Tres Haut Debit, Reseaux d'initiative publique," March 2017, p. 42 and 43."

Then, to capture potential differences in trends between aided and non-aided municipalities, we consider a specification where the effect of State aid is interacted with year dummies (columns (3) and (4)). For each specification discussed above, we estimate two regressions: (i) using OLS, and (ii) using the correction term for the presence of fiber infrastructure operators (Heckman).

In columns (1) and (2) in Table 9, the presence of State aid has a significant and positive impact on fiber coverage. Its average magnitude over the period 2014-2019 in the OLS estimation (column (1)) is 6.1%. When the correction term from the fiber entry model is included in the estimation (column (2)), the magnitude of the impact of State aid slightly increases up to 6.4%. The significant estimate of the Mills ratio indicates that the OLS estimates suffer from a sample selection bias.

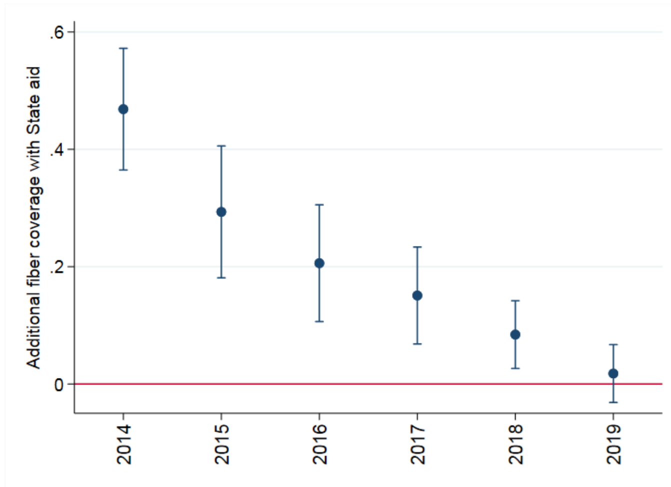
In columns (3) and (4) in Table 9, we see that the positive impact of State aid on fiber coverage is large at the beginning of the period, but decreases over time. The coefficient of the Mills ratio is again positive and statistically significant, suggesting that the OLS estimates suffer from a sample selection bias. Based on the estimates from column (4) in Table 9, Figure 5 shows the evolution of the impact of State aid on fiber coverage over time. The additional coverage in aided municipalities was 47% in 2014, 29% in 2015, 21% in 2016, 15% in 2017, and 8% in 2018.[33] There is no evidence that State aid allowed for significantly higher coverage in 2019.

We include in the models a number of control variables to account for the heterogeneity of local markets, which we expect to have a significant impact on the deployment of fiber. The effects are qualitatively similar across specifications, except for differences with respect to the level of significance of certain variables. In specification (4), a higher level of fiber coverage in neighboring municipalities in the previous period is associated with higher levels of fiber coverage in the municipality. This confirms the existence of geographic dependence in fiber deployment. The coefficient of income is negative and statistically significant at the 90% level. This suggests that income effects are dominated by the cost effects. Fiber coverage in private and mixed initiative zones is higher than in the public initiative zone. Moreover, coverage increases as the quality of the legacy copper network decreases. This result reinforces the evidence of a replacement effect that we also find when estimating the entry model. The coefficients of yearly dummies are positive, statistically significant and they increase over time. This is intuitive as deployment is an incremental process. Finally, we include in the estimations department dummy

[33]The impact of State aid on coverage in years 2015-2019 is computed by adding each interaction coefficient to the coefficient of the State aid dummy.

variables to control for differences in attractiveness of municipalities which belong to them. The majority of them are highly significant.

Figure 5: Evolution of the impact of State aid on fiber coverage.



Note: Estimates from column (4) in Table 9 where the dependent variable is the fiber coverage rate at the municipality level. Each point represents the additional coverage rate in aided municipalities. For example, in 2015 aided municipalities had additional 29% coverage with respect to non-aided municipalities. The vertical lines represent the confidence intervals at 95%.

Our results suggest that the presence of State aid in municipalities has allowed higher fiber coverage, particularly at the beginning of the period. As time passes, the gap with non-aided municipalities seems to be closing. This may reflect a reduction of uncertainties regarding demand or costs for private operators, which deploy fiber infrastructure in non-aided municipalities.

7 Conclusion

In this paper, we exploit a rich data set on fiber deployment, State aid, and local market characteristics in France to analyze the efficiency and the impact on fiber coverage of State aid granted through the French Broadband Plan (*Plan France Très Haut Débit*). First, we study the determinants of entry into fiber and evaluate the efficiency of the Plan. Second, we assess the impact of State aid on fiber deployment, controlling for the endogeneity of fiber entry.

State aid is an important policy tool for the deployment of broadband networks in rural and low-density areas, where private operators may have no incentive to invest. However, State aid is subject to control, as it may distort competition or crowd-out private investment. In particular, it is important to corroborate that State aid is granted in areas where market operators would not normally choose to invest.

Our results suggest that the French Broadband Plan was successful in covering areas that would not have been covered otherwise, but at the cost of some level of crowding out. In 80% of cases, State aid benefited municipalities where private entry would not have occurred during the year when State aid became effective. If we consider the possibility of entry by a private operator in the years after State aid took effect, we find that 64% of the aided municipalities would not have been covered without the Plan. Crowding out may result from the uncertainties surrounding investment decisions, in terms of levels of cost or demand, or the process itself, with the impatience of local authorities to obtain coverage.

When evaluating the Plan's efficiency, we also studied the determinants of fiber entry. We find that local market characteristics, such as the size of the market and income, are important determinants. Interestingly, we also find evidence of a strong geographic dependence in fiber entry and the presence of a replacement effect from the legacy copper network in fiber entry decisions. We also find that fiber entry becomes easier over time.

We use our estimates to compute the cost of 'efficient' and 'inefficient' State aid in our two cases based on the average cost of State aid per line in a municipality. According to our estimates in 2019 in the 'myopic' scenario 'efficient' State aid corresponds to 1,960 million Euros and 'inefficient' to 243 million Euros. In the '3 years' scenario the respective numbers are 1,301 and 902 million Euros. These numbers represent upper bound because we use total number of lines in municipalities in the calculation which may be higher than the number of lines which received State aid.

Next, we analyze which infrastructure operators invest predominantly in municipalities with State aid identified as inefficient. We identify a few problematic cases which can be investigated further by the authorities.

We also study the impact of State aid on fiber coverage, controlling for the endogeneity of fiber entry. Our analysis suggests that the French Broadband Plan allowed higher fiber coverage rates in aided municipalities, especially at the beginning of the period of analysis. This effect decreases over time. At the end of the observation period, there is no difference between aided and non-aided municipalities. Our interpretation is that, due to strong uncertainties about demand and costs, private operators chose to deploy their networks progressively in local ares, leading to a gap in coverage between aided and non-aided municipalities. As those uncertainties were resolved over time, the gap also decreased and eventually vanished.

Due to data limitations and our focus on infrastructure operators, we are unable to study the impact of State aid on competition between Internet service providers, or the impact of fiber competition on deployment. The analysis of entry in the downstream market for fiber service provision to residential and/or business consumers is an interesting avenue for future research. Moreover, we assume that there is no bias of favoritism or corruption in the granting of aid in local markets. For instance, there might be political factors (e.g., differences in the engagement of constituents or local representatives across markets, political orientation at the regional, departmental and local levels) influencing the location and timing of State aid. This question may be a subject of further research on State aid.

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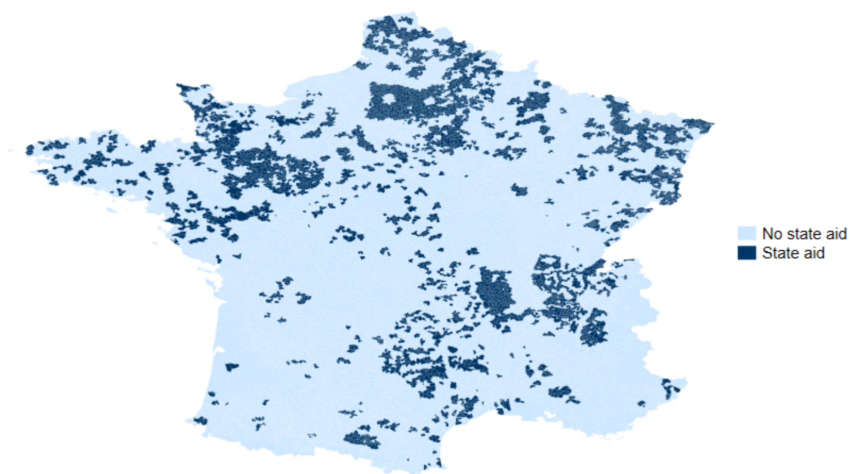
Appendices

Appendix A1 Additional Tables

Figure 6: Municipalities benefiting from State aid as of 2019Q4



Source: ANCT.

Table 9: Fiber coverage in municipalities.

Dep. Var: Fiber coverage rate	(1) OLS	(2) Heckman	(3) OLS	(4) Heckman
State aid (dummy)	0.061**	0.064**	0.518***	0.468***
	(0.030)	(0.030)	(0.043)	(0.053)
State aid (dummy) * 2015			-0.196***	-0.175***
			(0.034)	(0.033)
State aid (dummy) * 2016			-0.299***	-0.262***
			(0.042)	(0.046)
State aid (dummy) * 2017			-0.359***	-0.318***
			(0.041)	(0.049)
State aid (dummy) * 2018			-0.434***	-0.384***
			(0.037)	(0.046)
State aid (dummy) * 2019			-0.506***	-0.451***
			(0.035)	(0.048)
Level of coverage in neigbor t-1	0.378***	0.489***	0.381***	0.451***
	(0.039)	(0.034)	(0.037)	(0.038)
Log(Income)	-0.070*	-0.066*	-0.075**	-0.072*
	(0.036)	(0.037)	(0.036)	(0.037)
Type of initiative zone (ref: public)				
Private initiative	0.063**	0.108***	0.065**	0.093***
	(0.030)	(0.033)	(0.031)	(0.032)
Mixed initiative	0.073	0.135**	0.076	0.115*
	(0.058)	(0.058)	(0.059)	(0.059)
Copper loss (ref: <=20dB)				
20dB-30dB excellent	0.019	0.030*	0.022	0.028*
	(0.015)	(0.015)	(0.015)	(0.015)
30dB-40dB very good	0.065***	0.072***	0.067***	0.071***
	(0.018)	(0.018)	(0.018)	(0.018)
40dB-50dB good	0.111***	0.117***	0.112***	0.116***
	(0.023)	(0.023)	(0.023)	(0.023)
50dB-60dB poor	0.147***	0.153***	0.147***	0.151***
	(0.026)	(0.026)	(0.026)	(0.026)
>=60dB bad	0.154***	0.156***	0.155***	0.156***
	(0.030)	(0.030)	(0.030)	(0.030)
Year dummies (ref 2014)				
y2015	0.052***	0.047***	0.031**	0.030**
	(0.016)	(0.013)	(0.012)	(0.012)
y2016	0.090***	0.085***	0.064***	0.064***
	(0.024)	(0.022)	(0.021)	(0.020)
y2017	0.112***	0.112***	0.093***	0.095***
	(0.027)	(0.024)	(0.026)	(0.025)
y2018	0.164***	0.163***	0.166***	0.165***
	(0.029)	(0.026)	(0.031)	(0.029)
y2019	0.195***	0.197***	0.234***	0.232***
	(0.030)	(0.028)	(0.032)	(0.030)
Mills ratio		0.050***		0.032**
		(0.017)		(0.016)
Department dummies	Yes	Yes	Yes	Yes
Constant	0.758**	0.603	0.769**	0.670*
	(0.364)	(0.385)	(0.364)	(0.382)
Observations	81,616	81,616	81,616	81,616
Adjusted R-squared	0.289	0.291	0.296	0.297

Note: Robust standard errors in parentheses (clustered at the department level). Symbols *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table A.1: List of projects eligible to State aid in the framework of the French Broadband Program as of January 2021

Project code	Departments/region	Project code	Departments/region
CD01	Ain	CD40	Landes
CD02	Aisne	LIMO	Limousin
PACA	Alpes-de-Haute-Provence & Hautes-Alpes	CD42	Loire
CD06	Alpes-Maritimes	CD44	Loire-Atlantique
ALSA	Alsace	CD45	Loiret
ARDR	Ardèche & Drôme	CD41	Loir-et-Cher
CD09	Ariège	CD46	Lot
CD10	Aube	CD47	Lot-et-Garonne
CD11	Aude	CD48	Lozère
AUVE	Auvergne	CD49	Maine-et-Loire
CD12	Aveyron	CD50	Manche
CD13	Bouches-du-Rhône	C972	Martinique
BRET	Bretagne	CD53	Mayenne
CD14	Calvados	C976	Mayotte
CD16	Charente	CD57	Moselle
CD17	Charente-Maritime	CD58	Nièvre
CD18	Cher	NPDC	Nord-Pas-de-Calais
CORS	Corse	CD60	Oise
CD21	Côte-d'or	CD61	Orne
CD79	Deux-Sèvres	CD64	Pyrénées-Atlantiques
CD24	Dordogne	CD66	Pyrénées-Orientales
CD25	Doubs	C974	Réunion
CD91	Essonne	C977	Saint-Barthélémy
CD27	Eure	C975	Saint-Pierre-et-Miquelon
CD28	Eure-et-Loir	CD71	Saône-et-Loire
CD30	Gard	CD72	Sarthe
CD32	Gers	CD73	Savoie
CD33	Gironde	CD77	Seine-et-Marne
GDES	Grand Est	CD76	Seine-Maritime
C971	Guadeloupe	CD80	Somme
C973	Guyane	CD81	Tarn
CD31	Haute-Garonne	CD82	Tarn-et-Garonne
CD52	Haute-Marne	CD94	Val-de-Marne
CD70	Haute-Saône	CD95	Val-d'oise
CD74	Haute-Savoie	CD83	Var
CD65	Hautes-Pyrénées	CD84	Vaucluse
CD34	Hérault	CD85	Vendée
CD36	Indre	CD86	Vienne
CD37	Indre-et-Loire	CD88	Vosges
CD38	Isère	CD89	Yonne
CD39	Jura	CD78	Yvelines

Table A.2: Comparison of correct prediction rates across models

Year	Model I	Model II	Model III
2014	98.8%	98.7%	98.8%
2015	98.4%	98.2%	98.4%
2016	97.1%	96.7%	97.0%
2017	96.7%	96.3%	96.3%
2018	95.5%	95.1%	94.2%
2019	92.8%	91.7%	89.9%
All	97.0%	96.7%	96.4%

Note: Prediction rates are calculated as the ratio between the number of correct predictions (for entry and no entry) and the total number of observations. This ratio is calculated only for the 27,601 municipalities which do not benefit from State aid in the period 2014-2019.

Table A.3: Fiber entry and exit in years 2014-2019.

	Number of infrastructure operators (Nb fiber_t)					
Nb fiber_{t-1}	0	1	2	3	4	5
0	744 115	10 901	259	40	0	0
1	0	64 875	289	50	1	0
2	0	0	3 839	72	2	0
3	0	0	0	1 712	24	0
4	0	0	0	0	417	2
5	0	0	0	0	0	34

Note: 826,632 observations for 34,443 municipalities for the period 2014-2019. We observe entry, but no exit.