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The Impact of Fiber Optic Deployment on the Economic Development of Rural Areas in France

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"They did not know it was impossible, so they did it."
Mark Twain

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1. Introduction.

Access to high-speed broadband has become a central issue in territorial development policies and the fight against digital inequality. In many developed countries, the rollout of fiber optic networks is presented as a driver of growth, competitiveness, and attractiveness, including for rural areas that have long been excluded from major digital infrastructure. However, the actual economic impact of such investments remains widely debated particularly in low-density areas where the expected returns are less immediate.

This thesis evaluates the impact of the progressive deployment of fiber optic networks on the economic development of rural French municipalities between 2016 and 2024. Unlike cross-sectional approaches, our identification strategy relies on a natural experiment: the rollout schedule of the *Plan France Très Haut Débit*, which connected municipalities based on technical, budgetary, and political criteria largely independent of their local economic trajectory. This temporal heterogeneity enables the use of a staggered-treatment difference-in-differences methodology, following the approach of Callaway & Sant'Anna (2021).

Using a municipality-level panel dataset covering all rural areas in France (INSEE density levels 5 to 7), we estimate average treatment effects of fiber deployment on several outcomes: median income, unemployment rate, firm creation, real estate prices per square meter, and resident population. The data are drawn from INSEE, DARES, ARCEP, the DVF real estate transaction database, and the SIRENE business register.

The results reveal substantial heterogeneity in the impact of fiber:

- Median income increases significantly from the first post-treatment year, with an average gain of +5% three years after deployment.
- The unemployment rate decreases slowly but steadily, with a significant effect in more densely populated municipalities.
- Business creation does not respond positively to fiber rollout; in fact, a slight delayed negative effect is observed.
- Real estate prices decline in the most isolated areas, suggesting either a targeting effect or a depreciation dynamic.
- Population continues to decrease after fiber installation, especially in the most sparsely populated zones.

These results are robust to several validation checks, including placebo tests, heterogeneity analysis by density level, and pre-trend assessments. The economic effect of fiber thus appears to depend on structural territorial characteristics: denser rural municipalities (level 5) benefit most clearly, while more remote areas (level 7) remain peripheral to the dynamic initiated by fiber access.

This work calls for a reconsideration of how digital infrastructure policy is territorially targeted. Rather than being a universal remedy, fiber optics function more as an amplifier of pre-existing local potential than as an automatic corrective tool. To ensure that digital infrastructure generates widespread and equitable benefits, it must be coupled with targeted support policies that take into account the economic, social, and demographic structure of each territory.

The thesis is structured as follows: Section 1 introduces the context and challenges related to fiber deployment in rural areas. Section 2 reviews the economic literature on digital infrastructure and local impact. Section 3 outlines the identification strategy and econometric methodology. Section 4 describes the dataset and panel construction. Section 5 presents the empirical strategy. Section 6 reports the main results. Finally, Section 7 explores heterogeneous effects and concludes with policy implications.

2. Literature Review.

2.1. Theoretical Framework and Key Issues.

The way digital infrastructure, particularly fiber-optic broadband, shapes territorial development rests on two major theoretical pillars: on the one hand, the notion of the digital divide, which emphasizes how unequal access to technology can exacerbate social and economic inequalities; on the other hand, local economic development theory, which focuses on how territories grow and transform through their own resources and internal dynamics (Gratton & Packard, 2018).

In practical terms, deploying fiber-optic broadband is not just about faster internet—it enables firms to increase efficiency, fosters job and startup creation, attracts new residents, and can even contribute to the renewal and revaluation of older housing stock.

To structure our reading of the existing literature, we rely on three key analytical dimensions (Gratton & Packard, 2018; Moretti, 2019):

- Productivity and employment: How does high-speed internet affect local productivity gains, wages, and employment levels?
- Innovation diffusion: What are the barriers and enabling factors that determine whether firms and households actually adopt these new technologies?

- Geographic spillovers: How do the effects of broadband deployment spread spatially, through increased attractiveness of neighboring municipalities, changes in housing prices, or other regional dynamics?

This threefold framework underpins our empirical approach using staggered difference-in-differences: it informs our choice of outcome variables (median income, unemployment rate, firm creation, real estate prices), and helps formulate clear hypotheses about the channels through which fiber-optic infrastructure influences rural economic development.

We now turn to the first key mechanism: the productivity gains associated with broadband expansion and their potential effects on local wages.

2.2. Productivity, Employment, and Wage Structure.

In connection with our first analytical dimension, productivity and employment, Forman, Goldfarb and Greenstein (2012) compared U.S. counties before and after the arrival of broadband to assess whether local wages changed. They used a classical difference-in-differences model with county and year fixed effects.

However, two issues weaken their identification strategy. First, other events such as factory openings or closures, or shifts in local policies, may coincide with broadband rollout and bias the results. Second, the mere presence of a broadband network does not guarantee that it is actually used by residents or businesses.

Their findings show a general increase in productivity, but this is not always followed by a rise in wages across the board. Rural areas and low-skilled jobs benefit less. Moretti and Jensen (2017) confirm this: even when fiber is available, it takes time for individuals to acquire the digital skills needed to benefit from it.

Applying these findings to rural France is not straightforward. The industrial structure and vocational training systems differ from those in the United States. This is why our study uses a staggered DiD strategy, with placebo tests to verify the absence of pre-trends, and lag analyses to capture effects over time.

To better reflect income distribution, we use the median income instead of the average, and we add variables such as population density and network maturity.

After examining how high-speed internet affects wages, we turn to its influence on community behavior and local dynamics, drawing on Falck, Gold and Heblich (2014).

While DiD already reveals significant labor market dynamics, it is useful to see how the same method applies to other areas such as civic participation, before extending the discussion to broader economic development.

2.3. DiD Method in a Non-Economic Context.

Falck, Gold, and Heblich (2014) applied a difference-in-differences approach to assess the impact of Internet rollout on voter turnout in nearly 400 German municipalities. By comparing, year by year, the newly connected municipalities to those that remained offline, they observed a significant increase in turnout immediately after service became available, with no evidence of anticipation effects before the network was operational. Their empirical strategy provides valuable insights for calibrating our own tests, including placebo and lead-lag analyses, in a rural economic setting.

However, in an economic context, it often takes several years for broadband access to influence productivity, wages, or business creation. This delay reflects the time needed for individuals and firms to adapt, invest, and develop relevant skills. This is precisely what motivated us to extend our initial observation window from 2018–2021 to the full period 2016–2024. By doing so, we are able to capture not only the short-term adjustments following each phase of broadband rollout, but also the more persistent and structural impacts on rural economic development.

After drawing lessons from this civic application, we return to the strictly economic field, where rural broadband intersects with entrepreneurship and employment dynamics, as examined by Gonzales (2020).

2.4. Entrepreneurial Dynamics in Rural Areas.

The policy brief by Gonzales (2020) and the empirical study by Whitacre et al. (2014) describe mixed effects of broadband access on employment and the growth of startups. Both sources highlight the importance of technological maturity and the time required for local actors to adapt.

Gonzales provides a comprehensive overview of research on rural broadband deployment in the United States. He compiles findings from diverse methodological approaches, including panel regressions and quasi-experimental designs such as regression discontinuity (RDD). The results remain mixed. Some studies point to a positive impact on employment and firm creation. Others find marginal or delayed effects, suggesting that the benefits of broadband depend on the local capacity to adopt and integrate digital tools.

Whitacre et al. (2014) go further by conducting a detailed econometric analysis of several rural U.S. counties. They apply fixed-effects panel models, combined with an instrumental variable strategy based on proximity to existing infrastructure. Their results show that when controlling for unobserved county characteristics and macroeconomic shocks, the arrival of broadband significantly increases the number of new businesses per capita. However, this effect only becomes visible two to three years after the infrastructure is installed.

These studies informed two important choices in our own empirical design. First, we include both the unemployment rate and the business creation rate in our analysis in order to capture different dimensions of local labor market dynamics. Second, we extend our observation window to ensure that we can detect delayed effects that might only emerge several years after the initial deployment of fiber.

Beyond entrepreneurship, it is also helpful to compare fiber optics to traditional infrastructure investments. This broader perspective allows us to assess whether the mechanisms and expectations associated with digital infrastructure differ from those observed in transport or energy systems.

2.5. Physical infrastructures versus digital infrastructures.

Kandilov and Renkow (2010) explore the core of the literature on large-scale physical infrastructure projects such as roads, water systems, and electricity grids, focusing on their capacity to transform rural economies. They leverage both the timeline and spatial distribution of public investments and compare the treated counties with similar non-treated ones. This approach ensures that the estimated effects stem from the infrastructure itself rather than from endogenous selection by policymakers.

Their findings suggest that infrastructure investments lead to sustained increases in productivity, income per capita, and land value. However, these effects only become visible after a delay of several years. This time lag reflects the period required for the infrastructure to be built, adopted, and fully integrated into local agricultural or industrial practices.

Although fiber optics may share the ambition of being a transformative tool for rural development, it exhibits two important distinctions. First, the deployment of broadband tends to be faster than that of a highway or water network. However, its value depends heavily on the ability of businesses and households to adopt digital technologies, which is a more diffuse and less observable process than physical usage of a new road. Second, the exogeneity of the treatment is potentially more fragile. The decision to install fiber in a given municipality may not be fully disconnected from local economic performance, especially when public funding follows political or budgetary priorities rather than strictly developmental criteria.

These insights reinforce the importance of including strong controls for time-invariant heterogeneity through fixed effects at the municipal level. They also justify the decision to extend the observation window to capture both short-term and delayed effects, similar to the timeframes observed by Kandilov and Renkow for traditional infrastructure projects.

To complete the literature review, we now shift to a broader macro-regional scale to examine how information and communication technologies (ICT), particularly broadband, influence economic growth across the European Union.

2.6. Macro-regional effects of ICT.

At the European Union level, Billon, Lera-López, and Marco (2017) show, using Granger causality tests and panel data regressions, that it is the combination of rapid broadband rollout and intensive adoption of ICT (Information and Communication Technologies) that drives GDP growth and investment among member states. In concrete terms, a country with widespread access and strong digital integration by firms tends to generate new industries, improve productivity, and strengthen competitiveness. These mechanisms, when accumulated at the local level, can stimulate territorial economic development.

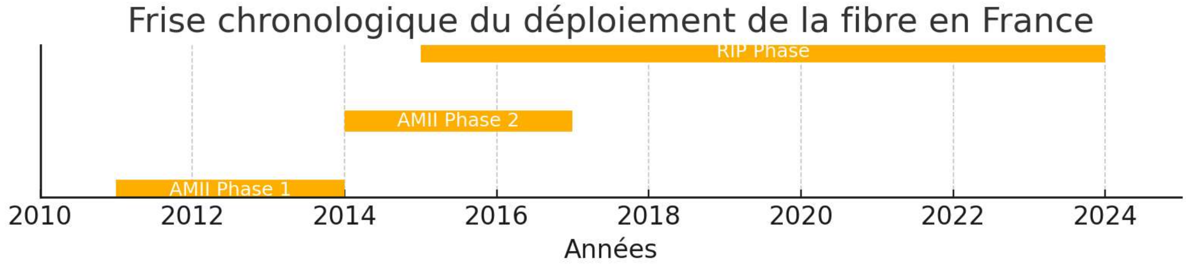
To translate these "macro-to-local" links, one can check whether national trends (GDP, investment) and local outcomes (median income, unemployment rate, business creation) evolve in parallel, or apply causality tests (such as Granger tests) to groups of municipalities. This can be complemented with indicators like real estate prices, population density, or net migration balances to capture the full range of transmission channels, including innovation, labor markets, and residential attractiveness, through which broadband impacts territorial development.

This continental perspective encourages us to place France's broadband deployment within its specific institutional and technical context, drawing on data and frameworks provided by INSEE and ARCEP.

2.7. Institutional Context in France.

The INSEE reports on the digital transition of territories and the ARCEP publications outlining the two major phases of fiber rollout provide essential institutional insight (see timeline below).

Figure 1: Chronological Timeline of Fiber Deployment in France.



- **AMII Phase (2011–2017):** The so-called "Call for Expression of Investment Intent" agreements were encouraged by the state and led by private operators in urban or economically attractive areas. This market-driven approach aimed at profitability, which implies a potential bias: the first areas to be connected were often already more dynamic. This questions the exogeneity of the treatment unless initial characteristics are carefully controlled.
- **RIP Phase (2015–2024):** These "Public Initiative Networks" are funded by local authorities and public funds, specifically targeting less profitable areas, often rural zones. Unlike the AMII phase, where deployment followed mainly market logic, RIPs reflect a commitment to equitable territorial coverage. This strengthens the exogeneity of the treatment in our study.

The AMII and RIP zones therefore make it possible to assess whether the effects vary depending on whether fiber deployment was market-driven or publicly initiated. This justifies the extension of the observation window. The combination of staggered cohorts and a long observation period reinforces the credibility of the quasi-exogeneity assumption and enhances the reliability of causal estimates.

2.8. Summary and Outlook.

This literature review highlights three key insights:

- Delayed and heterogeneous impacts: The economic effects of fiber deployment vary across sectors, skill levels, and population density, and often emerge only several years after installation.

- Need for a robust methodological framework: A standard DiD is insufficient; a staggered cohort-based DiD with placebo tests and lead/lag analysis is required to mitigate time-related and selection biases.

- Multidimensional effects: Income, employment, business creation, property prices, and demographic indicators must be analyzed together to capture the full range of transmission channels.

A summary of the main studies discussed is presented in Table 1 : Summary of Major Studies on the Impacts of Broadband and Fiber Optics. This table outlines the context, methodology, key results, and limitations for each author and serves as a reference throughout this literature review.

Table 1: Summary of Major Studies on the Impacts of Broadband and Fiber Optics

Study	Context	Method	Key Results	Limitations
Forman et al. (2012)	U.S. counties, wages	Bipartite DiD with fixed effects	Productivity ↑, wage premium varies by area	No placebo tests; coverage ≠ adoption
Falck et al. (2014)	German municipalities, voting	Simple DiD	Electoral participation ↑, no anticipation	Limited economic extrapolation
Whitacre et al. (2014)	U.S. rural counties, firm creation	Panel with fixed effects + instrumentation	Firm creation ↑ after 2–3 years	Diffusion mechanisms not detailed
Kandilov & Renkow (2010)	Rural public infrastructure	Quasi-experimental	Income and land value ↑ long-term	Traditional infrastructure focus
Gonzales (2020)	U.S., rural broadband (policy brief)	Mixed methods: panels, RDD	Mixed effects, delayed responses	No granular analysis of rollout modalities
Billon et al. (2017)	EU, GDP and ICT	Granger causality, panel data	Broadband + ICT adoption → GDP & investment ↑	Macro-level focus, limited territorial detail

Based on this literature, several testable hypotheses emerge for our own analysis:

- Fiber deployment is expected to significantly increase the median income at the municipal level.
- It is also expected to contribute to a reduction in local unemployment rates.
- Connected municipalities should exhibit a higher rate of business creation per capita compared to those not yet connected.
- Property prices are anticipated to rise sustainably following fiber deployment, reflecting a valuation effect linked to improved digital access.

Beyond these direct effects, spillover impacts may arise in neighboring areas. Moreover, the effective adoption of fiber is likely to foster remote work and enhance the residential appeal of rural areas.

In short, the literature underscores the importance of **delayed and heterogeneous effects**, the use of **staggered DiD methods**, and the relevance of a **multi-indicator panel**. These insights translate into precise hypotheses for this study and open new perspectives for future research on **intermunicipal spillovers** and **telecommuting**.

3. From the Difference-in-Differences Approach to the Callaway & Sant'Anna Method.

3.1. Foundations of the Difference-in-Differences (DiD) Model.

The Difference-in-Differences (DiD) approach is one of the standard frameworks for evaluating the impact of public policies when a treatment (in this case, fiber optic installation) is administered to a subset of units (municipalities) at a given point in time, and when time series data are available before and after the treatment.

This method compares the evolution of an outcome variable (for instance, the unemployment rate) between two groups and across two periods: before and after the treatment. It neutralizes any general trend affecting both treated and untreated municipalities, thereby isolating the variation attributable to fiber deployment.

The static DiD estimator is expressed as follows:

$$DiD = \left(Y_{treated,\,after} - Y_{treated,\,before}\right) - \left(Y_{control,\,after} - Y_{control,\,before}\right)$$

Where:

- $Y_{treated,before}$ and $Y_{treated,\,after}$, after are the average values of the outcome variable Y in the treated municipalities before and after fiber deployment;
- $Y_{control,before}$ and $Y_{control,after}$, after are the same averages for the untreated municipalities.

The DiD method therefore estimates the impact of fiber optics by comparing changes in a variable (such as the unemployment rate) in treated versus untreated municipalities, before and after the intervention. It relies on the assumption that, in the absence of fiber, both groups would have followed a similar trajectory.

To ensure the validity of the parallel trends assumption, pre-treatment dynamics are examined by plotting trends several years before fiber deployment and conducting placebo tests by simulating an earlier treatment date. If no effect is found before the actual deployment, this supports the claim that post-treatment differences are indeed attributable to fiber optics.

However, when municipalities receive fiber at different points in time, three major limitations arise:

- **No common treatment date**: The basic DiD framework assumes all units are treated simultaneously, which is not the case here.
- **Successive use of control units**: Some municipalities initially serve as controls, but are later treated, leading to overlapping and hard-to-interpret comparisons.
- **Uncaptured timing dynamics**: The static model fails to reflect either anticipatory effects or delayed impacts.

These limitations naturally lead to the adoption of a staggered cohort approach.

3.2. Transition to Staggered Cohorts.

As previously discussed, the standard Difference-in-Differences (DiD) model assumes that all treated units receive the intervention at the same time. This assumption does not hold in the context of our study, since the deployment of fiber-optic broadband occurred progressively over time.

The French National Broadband Plan (Plan France Très Haut Débit, PFTHD) indeed scheduled a staggered deployment of fiber between 2018 and 2024. Some municipalities were connected as early as 2018 in pilot areas, while others were progressively covered until 2024. As such, each municipality i receives the treatment (fiber installation) at a specific date denoted $g_i \in \{2018, 2019, \ldots, 2024\}$, which defines its treatment cohort.

This situation renders the classical DiD estimator inapplicable. In a staggered adoption setting, municipalities treated later can serve as valid control groups for those treated earlier, as long as their treatment occurs after the observation date. For any year t, only municipalities such that $g_i > t$ can serve as valid comparators.

To capture this dynamic, we define an event-time variable:

$$\tau = t - g_i$$

This variable represents the number of years elapsed since the treatment for municipality i observed at date t. For instance, $\tau = 0$ corresponds to the year of fiber installation, $\tau = 1$ to one year after, and $\tau = -1$ to the year prior to treatment.

Table 2. Illustration of a staggered treatment design.

Observation year t	Treated cohorts before t	Untreated (valid control) cohorts at t
2019	Cohort 2018	Cohorts 2020, 2021, 2022, 2023, 2024
2020	Cohorts 2018, 2019	Cohorts 2021, 2022, 2023, 2024
2021	Cohorts 2018 to 2020	Cohorts 2022, 2023, 2024

This staggered cohort structure calls for a more flexible methodological framework, one that allows for the estimation of treatment effects specific to each cohort and each time period t , while ensuring valid control groups. This is precisely the approach introduced by Callaway & Sant'Anna (2021), which we detail in the following section.

3.3. The Callaway and Sant'Anna (2021) Method.

The method developed by Callaway and Sant'Anna (2021) provides a rigorous framework for estimating the effects of a treatment implemented progressively over time, as is the case with the deployment of fiber-optic broadband across French municipalities. Each municipality is treated at a specific date, and the average treatment effect is estimated for each cohort (defined by the year of fiber deployment) and each available observation period.

In this study, no fully exogenous variable was available to construct an external control group. Therefore, the adopted strategy relies on the endogenous construction of comparison groups. Specifically, a treatment variable is set to 1 for each year from which the municipality is considered connected, and 0 otherwise. At each observation year t , municipalities not yet connected (i.e., those for which $g_i > t$) automatically serve as controls for those already treated (i.e., $g_i \leq t$). This exclusion-based comparison logic ensures a consistent control group at each point in time, without the need for external sources.

Each average treatment effect is then expressed as a function of relative time to treatment, denoted as:

$$\tau = t - g$$

This formulation enables reconstruction of a dynamic treatment profile: before ($\tau < 0$), during ($\tau = 0$), and after ($\tau > 0$) the fiber installation year. The length of the observation window depends on data availability for each outcome variable, meaning that some dynamic effects are estimated over longer horizons than others.

Estimation is performed using the **"did"** package in R, which applies this method to panel data under staggered treatment timing. Municipality fixed effects are included to control for all time-invariant local characteristics (such as structural development, urban morphology, or baseline density). Year fixed effects are also added to account for macroeconomic or national shocks that could simultaneously influence all municipalities.

Confidence intervals are derived through bootstrap procedures, with standard errors clustered at the municipal level to address temporal dependence across observations. This approach provides credible estimates of the causal effect of fiber deployment, while accounting for the progressive nature of treatment and the constraints inherent in the available data.

The successful implementation of this method hinges on the quality and structure of the underlying data. The following section describes the construction of the municipal panel, detailing the sources and preprocessing steps taken to estimate the dynamic impacts of fiber deployment over the period from 2016 to 2024.

4. Datasets and Processing.

This section describes the origin, cleaning, and merging of the various statistical sources used to build our municipal panel covering the period from 2016 to 2024. The objective is to produce a coherent and comprehensive dataset suitable for estimating the dynamic effects of fiber deployment using the Callaway and Sant'Anna method.

4.1. Data Sources.

- **Fiber Coverage (ARCEP)**

The French telecommunications regulator ARCEP publishes quarterly files detailing FTTH network coverage across France. Since 2018, this data has been available at the municipal level in DBF format, indicating for each municipality the percentage of dwellings eligible for fiber optic access. Based on these files, a key variable for estimation was constructed: `fibre_it`.

To operationalize the treatment date, a municipality is considered treated in the year when its fiber coverage rate reaches or exceeds 80%. This threshold was chosen to reflect a sufficiently advanced stage of deployment for potential economic effects to materialize, while excluding marginal cases of partial coverage. The 80% benchmark is also consistent with conventions found in empirical studies addressing access to digital infrastructure.

The variable `fibre_it` is thus coded as 1 starting from the year in which the 80% threshold is reached, and 0 for all prior years. This binary coding allows us to identify, for each year and each municipality, whether it is considered connected to fiber or not.

Some of the variables used in the analysis (notably real estate prices and income) are available for years prior to 2018. To broaden the pre-treatment observation window, a backward projection assumption was adopted: when a municipality is identified as treated in 2018, it is also considered treated in 2016 and 2017. This approximation, applied only over a short interval, is deemed acceptable insofar as it allows the inclusion of a coherent pre-treatment period while minimizing the risk of misclassification.

Following processing, the constructed dataset includes, for each observation, the INSEE municipal identifier, a binary variable `fibre_it` indicating fiber status, and the corresponding year. This dataset forms the empirical foundation for the identification strategy implemented throughout the remainder of the thesis.

- **Unemployment (DARES-DEF-M)**

Unemployment data were obtained from the DARES, which annually publishes files containing the number of unemployed individuals by municipality. These data are available in Excel format under the DEF-M label, specifically in the "COM" sheet, which compiles information at the municipal level.

From these files, observations were extracted for each municipality, identified by its INSEE code, along with a variable indicating the total number of registered job seekers at the end of the month (all categories combined). An additional column was added to specify the corresponding year for each observation.

Based on this, a municipal unemployment rate was calculated by dividing the number of unemployed individuals by the total municipal population. This method allows for the creation of a standardized indicator, facilitating comparison across municipalities regardless of size. Subsequently, a logarithmic transformation was applied to the unemployment rate in order to stabilize variance and reduce sensitivity to outliers, in line with standard practices in panel data estimation models.

This processing ensures the integration of the unemployment variable into the empirical analysis, while guaranteeing statistical compatibility with the estimation methods used in the following chapter.

- **Business Creation (INSEE-SIRENE)**

Data on business creation were sourced from INSEE's SIRENE database, which records all new business registrations at the municipal level. This database is available annually from 2012 to 2023. The data were extracted from the "COM" sheet, which aggregates information at the commune level.

For each year and each municipality, identified by its INSEE code, the total number of business registrations was retrieved and organized into a structured dataset that includes a temporal variable indicating the year of observation. These data provide a direct measure of local entrepreneurial activity.

A business creation rate was then calculated by dividing the number of new registrations by the total municipal population, ensuring comparability across municipalities of varying sizes. To reduce the influence of extreme values and stabilize the variance, the rate was transformed using the natural logarithm. This transformation is consistent with the approach applied to other proportional or rate-based variables in the dataset.

The resulting variable allows the integration of municipal entrepreneurial dynamics into the estimation framework, serving as a potential indicator of the economic impact of fiber deployment.

- **Real Estate Values (DVF)**

Data on real estate prices were sourced from the *Demande de Valeurs Foncières* (DVF) database, made publicly available by the French government. This dataset records, for each year and each municipality, all real estate transactions that took place in the territory, with a high level of detail regarding the type, date, and amount of each transaction.

For this study, data were extracted for the period from 2016 to 2023. A filtering process was applied to retain only residential-use transactions, thereby excluding agricultural, commercial, or undeveloped land properties. Among the variables available, the average price per square meter was selected as the primary indicator, as it offers a concise measure of local land value.

The resulting structured dataset includes, for each observation: the INSEE municipal code, the transaction year, and the average price per square meter. This variable, serving as a proxy for residential attractiveness and real estate market dynamics, constitutes a relevant indicator for assessing the potential effects of fiber optic deployment on territorial valuation.

- **Taxable Income (Filosofi-INSEE)**

Fiscal data were obtained from the *Filosofi* files published by INSEE, which provide socio-fiscal indicators at the municipal level. These files are available for the period 2015–2021 and include key variables such as median income, tax population, number of tax-filing households, and the share of taxable households.

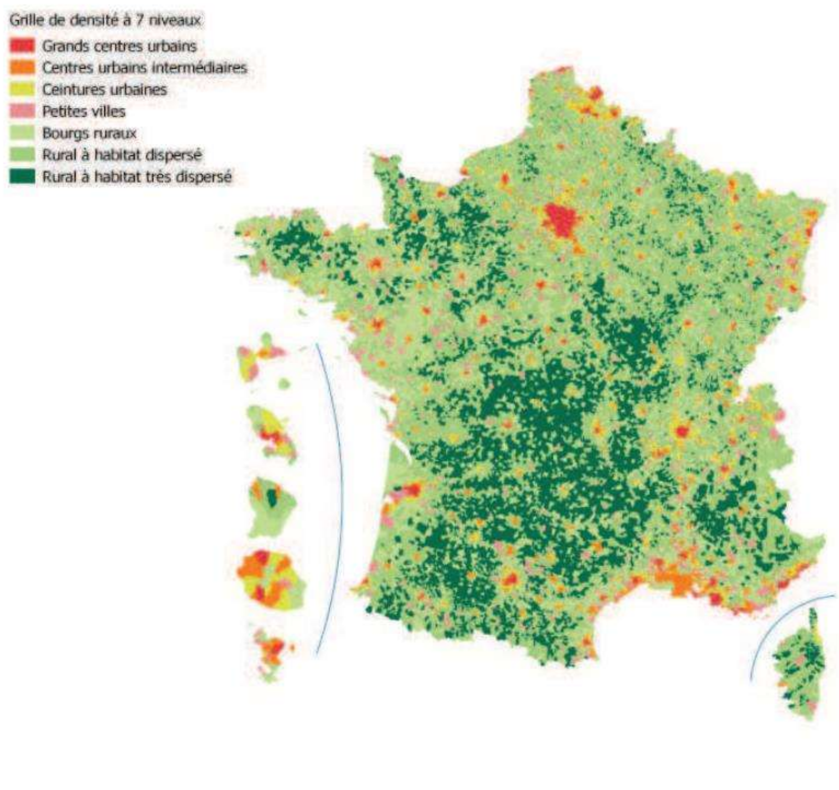
However, upon review, only two variables were consistently available for rural municipalities throughout the full period: median income and the fiscal population. Since each file is structured as an independent annual dataset, the data were harmonized by selecting the INSEE code for each municipality, adding a column for the reference year, and merging all files into a single panel covering the 2015–2021 period.

The median income variable, expressed in constant euros, serves as a key indicator of local living standards and enables an assessment of whether the arrival of fiber optic infrastructure is associated with favorable economic dynamics in the targeted territories.

- **Density and Geographical Characteristics**

Figure 2 : 7-Level Municipal Density Grid

Figure 11 : Grille de densité communale à 7 niveaux



Champ : France, limites territoriales communales en vigueur au 1er janvier 2021.

Municipal Density Grid – Working Paper No. 2022-18. Simon Beck, Marie-Pierre De Bellefon, Jocelyn Forest, Mathilde Gerardin, David Levy.

Each year, INSEE publishes a municipal density grid that classifies French municipalities into seven levels, ranging from the most urban (level 1) to the most rural (level 7). This typology is based on criteria such as population size, the continuity of built-up areas, and spatial concentration. It constitutes an official benchmark for characterizing the degree of urbanization of a territory.

Data are available for each year from 2015 to 2024. For each vintage, files were imported and the following information was extracted: the INSEE code of the municipality, its density level (from 1 to 7), and its reference municipal population.

These two variables play a key role in the analysis: the density level is used to restrict the final sample to rural municipalities (levels 5 to 7), in line with the aim of the dissertation, while the municipal population is used as the denominator in the calculation of various rates (e.g., unemployment, business creation). These density and population data were subsequently merged with the other datasets to construct the final panel.

4.2. Data Cleaning, Typing, and Harmonization.

To ensure consistency and accurate merging of the various statistical sources, the INSEE codes of each municipality were standardized and converted into five-character strings. This operation ensures a perfect match between datasets, regardless of their original format.

During the data import process, each variable was explicitly typed according to its nature: identifiers (INSEE codes) were treated as character strings, years as integers, and monetary amounts, rates, or ratios as double-precision numeric variables.

The rates used in the analysis (unemployment rate, business creation rate) were calculated by dividing the number of unemployed individuals or business registrations by the municipal population. For the unemployment rate, a specific treatment was applied. Until 2021, the fiscal population from the Filosofi files was used as the denominator, as it more directly reflects the active population. Beyond 2021, due to the unavailability of fiscal data, the municipal population from the density files was used instead. This choice is based on the assumption that, in rural contexts where the gap between the fiscal and municipal populations is generally small, this substitution does not introduce significant bias into the analysis.

To stabilize variance and limit the influence of extreme values, a logarithmic transformation was applied to both the unemployment rate and the business creation rate.

Finally, additional cleaning was carried out: duplicates identified based on the (INSEE code, year) combination were removed, and observations with more than 10% missing values on key variables were excluded from the final panel. These steps aim to ensure the statistical quality of the data in preparation for the forthcoming econometric estimations.

4.3. Construction of the Final Panel.

Once each dataset was cleaned, the various sources were merged using a left join, based on the INSEE code of the municipalities and the year of observation as keys. The order of merging followed the logic below: the reference dataset was the one related to fiber coverage, to which were successively added the data on municipal density, then indicators on unemployment, business creation, property values, and finally the fiscal data from Filosofi.

This method ensures that all municipalities and years available in the main dataset (fiber) are preserved, even in the absence of data on some secondary variables. Missing values are coded as NA, maintaining the dataset's structure while ensuring compatibility with panel estimation tools.

After merging, several filtering steps were carried out to adapt the dataset to the empirical objectives of this thesis. Only municipalities classified as rural (according to levels 5 to 7 of the INSEE density grid) were retained, to focus the analysis on the areas relevant to the research question. A variable called `gname` was created to identify, for each municipality, the year it first reached the status of being fibered (i.e., the year in which coverage exceeded the 80% threshold).

Finally, the 2024 cohort was excluded from the sample, as it does not allow for post-treatment effects to be observed within the chosen time window. The final panel, named `panel_for_did_2016_2024`, thus covers the period from 2016 to 2024 and contains, for each municipality, variables for fiber coverage, density level, unemployment rate, business creation rate, average property price per square meter, median income, and population. This dataset is directly usable in the following chapters for the estimation of the dynamic effects of fiber deployment.

5. Identification Strategy and Econometric Implementation.

In this chapter, we present the identification logic, the econometric specification, and the operational process used to measure the dynamic impact of fiber optic deployment on rural municipalities. We do not delve into technical details (e.g., R code), which are instead reserved for the methodological appendix.

The credibility of this approach is empirically assessed in the following chapters through pre-trend graphs and placebo tests.

5.1. Identification Principle.

The deployment of fiber optics in France followed a schedule largely determined by technical, budgetary, and institutional considerations, often unrelated to the local economic conditions of municipalities. This structural feature of the “Plan France Très Haut Débit” allows us to consider the timing of fiber rollout as quasi-exogenous that is, not directly correlated with the specific socio-economic trajectories of each territory.

Based on this assumption, the identification strategy relies on a staggered difference-in-differences (DiD) approach, as proposed by Callaway & Sant’Anna (2021). Each municipality is assigned to a treatment cohort defined by its year of fiber deployment, denoted as g_i. Municipalities that are never connected during the analysis period may be considered untreated across the entire horizon.

At each time point t, the treatment effect is estimated by comparing treated municipalities (i.e., those for which $g_i \leq t$) to those not yet treated (i.e., $g_i > t$). This structure allows for the definition of valid control groups composed exclusively of units that have not yet been exposed to treatment at the time of observation.

Identification relies on the **conditional parallel trends assumption**: in the absence of fiber deployment, the economic indicators (median income, unemployment rate, business creation rate, real estate prices) would have followed similar trajectories between treated and not-yet-treated municipalities. This assumption will be empirically assessed in the following chapters using pre-trend graphs and placebo tests.

5.2. Econometric Specification.

For each outcome variable Y_{it}, the estimation of the effects of fiber deployment relies on the methodological framework proposed by Callaway and Sant’Anna (2021), implemented using the `att_gt()` function from the `did` package in R. This method estimates, for each treatment cohort g and each observation year t, an average treatment effect $ATT(g,t)$, which is then reorganized according to the time relative to treatment, noted as $\tau = t - g$.

The specification used is as follows:

$$Y_{it} = \mu_i + \delta_t + ATT(g_i,t) + \varepsilon_{it}$$

where:

- μ_i denotes an individual fixed effect, constant over time, specific to each municipality i, controlling for unobserved structural characteristics (such as location, size, socio-economic profile).

- δ_t represents a time fixed effect, capturing aggregate shocks that affect all municipalities in the same year (for example: national economic conditions, pandemics, fiscal policy).
- $ATT(g_i,t)$ is the average treatment effect for cohort g_i in year t , estimated by comparing treated municipalities to those not yet treated at time t , that is, those for which $g > t$.
- ε_{it} is the error term.

In the script, the treatment variable g_i was defined as the first year of fiber deployment starting in 2018, when a municipality reaches at least 80 percent FTTH coverage. Cohort 2024 was excluded, as it would not allow for post-treatment observation.

No explicit control variables were added to the specification (`xformla = ~1`), in line with recommended practice when fixed effects absorb most of the time-invariant and time-varying heterogeneity. The municipality identifier was created numerically (`com_id`) from the INSEE codes.

The effects $ATT(g,t)$ are then aggregated based on $\tau = t - g$ using the `aggte()` function with the option `type = "dynamic"`, in order to construct a dynamic temporal profile of the treatment effect. This curve makes it possible to observe the evolution of the effect in the years preceding ($\tau < 0$) and following ($\tau \geq 0$) fiber deployment, while testing the hypothesis of no anticipation effect (placebo) and whether the effect persists or fades.

Finally, for each variable analyzed (median income, log-unemployment rate, log-business creation rate, average price per square meter, and population), the aggregated results are summarized in synthesis tables. These present, for each value of τ, the estimated effect, its standard error, the associated z-score, and the corresponding p-value. These results are interpreted in the following chapters to assess the dynamic impact of fiber on rural territories.

5.3. Construction of the Aggregated Event Study.

To consistently capture the impact of the treatment across different fiber deployment cohorts, the estimated effects $\theta_{g,t}$ for each cohort g and each year t are converted based on the time relative to treatment, noted as $\tau = t - g$. This transformation allows us to visualize the average evolution of a variable in “event time.” In other words, it shows what happens several years before ($\tau < 0$) and after ($\tau \geq 0$) the deployment of fiber in a municipality.

Negative values of τ correspond to the pre-treatment period and serve as placebo tests. The absence of a significant effect before fiber deployment supports the validity of the parallel trends assumption. Positive values of τ, in contrast, reflect the post-treatment trajectory of the indicators, helping to identify the timing of the effects (delays, inertia, stabilization). The event time window used here covers τ values between minus six and plus six, depending on data availability for each variable.

The dynamic aggregation involves calculating, for each τ, a weighted average effect $ATT(\tau)$, combining results from all cohorts for which that relative period is observable. Each effect is weighted according to the relative size of its cohort within the panel. This aggregation yields a single curve centered on $\tau = 0$, which is visualized in the following chapters using `ggdid()` graphics. This curve forms the core of the dynamic impact analysis and facilitates comparison across variables and time periods.

5.4. Operational Implementation.

- **Preparation of the panel dataset**

The dataset used for the estimations was built by merging the various sources described in the previous chapter, using two keys: the INSEE code of the municipality and the year. The final panel includes the following variables: fiber coverage (binary), density level, unemployment (log-transformed rate), business creation (log-transformed rate), real estate price (euros per square meter), median income, municipal population, and the year of initial fiber deployment, noted g_i .

In line with the objective of the thesis, the sample was restricted to rural municipalities, defined as those with density levels 5 to 7 in the INSEE classification grid.

- **Estimation of Treatment Effects** $ATT(g,t)$

The estimation of treatment effects specific to each cohort g and each year t relies on the `att_gt()` procedure from the **did** package (Callaway & Sant'Anna, 2021) in R. For each outcome variable, this command:

- Identifies the treated groups at date t (i.e., municipalities that were fibered in year ggg) and the not-yet-treated groups (i.e., municipalities with $g_i > t$),
- Applies a difference-in-differences estimation, including both municipality and year fixed effects,
- Produces an object containing the estimates $\theta_{g,t}$ and their standard errors.

- **Agrégation dynamique et visualisation**

The estimated effects $\theta_{g,t}$ are then converted into relative time $\tau = t - g$ using the `aggte()` function with `type = "dynamic"`. This produces an aggregated event-study that captures the average evolution of each indicator in the years before and after fiber deployment, based on the set of cohorts observable at each value of τ.

The graphs generated using the `ggdid()` command provide a visual representation of this dynamic profile, with 95 percent confidence intervals, facilitating the interpretation of both trends and delayed effects.

- **Tabular Summary**

Finally, each event-study is accompanied by a summary table listing, for each value of τ, the estimated average effect $ATT(\tau)$, its standard error, the test statistic (z-score), and the associated p-value. These tables, generated using the `summarize_agg()` procedure, provide a detailed reading of the results for each dimension (income, employment, business creation, real estate, and population).

This section thus outlines the estimation architecture and processing pipeline, from raw data to dynamic effects. The corresponding empirical results are discussed in Section 5, while robustness checks and methodological validations are developed in Section 6.

6. Main Results and Discussion.

6.1. Main Results.

This section presents the estimated results for each outcome variable, following a consistent framework. For each indicator (median income, unemployment rate, business creation rate, real estate prices, and population), the analysis relies on dynamic effects estimated using the Callaway & Sant'Anna (2021) method, aggregated according to the relative time since treatment $\tau = t - g_i$.

The results are interpreted in terms of:

- **Direction** (positive or negative effect),
- **Magnitude**, expressed in euros or logarithmic terms depending on the variable,
- **Statistical significance**, based on confidence intervals or p-values derived from bootstrap procedures.

The pre-treatment effects (values where $\tau < 0$ serve as a test for the parallel trends assumption, while the post-treatment effects ($\tau \geq 0$) capture the fiber deployment's impact over time.

All detailed results (point estimates, standard errors, p-values) are reported in tables at the beginning of each sub-section, alongside the corresponding figures. The interpretation focuses on the economic relevance of the effects, taking into account their robustness and temporal consistency.

6.1.1. Median Income.

Figure 3 : Dynamic effect of fiber optic deployment on the median income of rural municipalities (event-study).

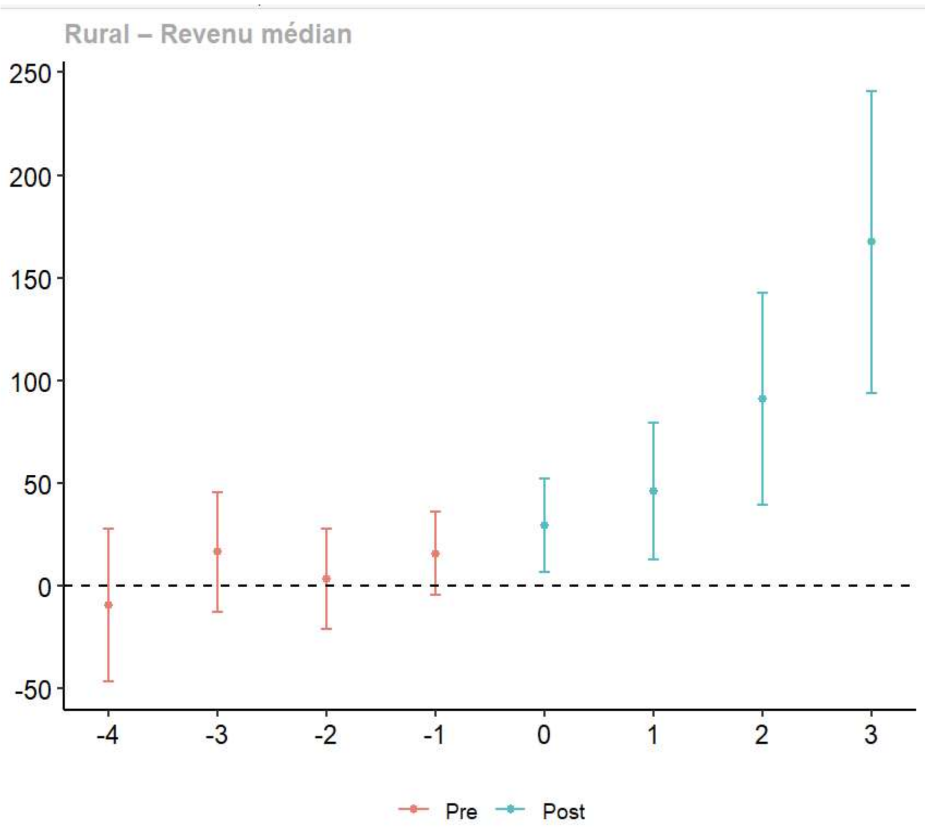


Table 3: Estimates of Average Treatment Effects (ATT) of fiber deployment on median income by event time (τ).

	event_time	att	se	z_value	p_value	variable
1	-4	-9.1459	13.2126	-0.6922	0.4888	Revenu médian
2	-3	16.6443	10.4008	1.6003	0.1095	Revenu médian
3	-2	3.3273	8.7413	0.3806	0.7035	Revenu médian
4	-1	15.8482	7.1749	2.2088	0.0272	Revenu médian
5	0	29.5020	8.0871	3.6481	0.0003	Revenu médian
6	1	45.9661	11.8936	3.8648	0.0001	Revenu médian
7	2	90.9885	18.3720	4.9526	0.0000	Revenu médian
8	3	167.3757	26.1262	6.4064	0.0000	Revenu médian

The results indicate a positive, increasing, and statistically significant effect of fiber optic deployment on the median income of rural municipalities, starting from the year of treatment ($\tau = 0$). The estimated effect intensifies year after year:

- $\tau = 0$: +€29.5 (p = 0.0003)
- $\tau = 1$: +€46 (p < 0.0001)
- $\tau = 2$: +€91 (p < 0.0001)
- $\tau = 3$: +€167 (p < 0.0001)

This last figure represents approximately +5% relative to a reference median income of €3,300, reflecting a strong cumulative dynamic in the years following fiber deployment. These results suggest that fiber may act as a lever for economic upgrading—possibly by improving labor market matching, working conditions, or business opportunities.

Prior to the treatment, the estimated effects are overall null and not significant ($\tau = -4\ to\ \tau = -2$), which supports the parallel trends assumption. However, year $\tau = -1$ shows a slight early increase (+€15.8, p = 0.027), which calls for cautious interpretation. This anomaly may reflect either anticipation effects or local pre-deployment adjustments (e.g., pre-construction hiring), to be investigated in robustness checks.

The associated graph visually confirms the steady increase in income gains post-treatment, with narrow confidence intervals between $\tau = 0\ and\ \tau = 3$, further reinforcing the statistical robustness of the findings.
The installation of fiber optics is associated with a significant and gradually increasing rise in median income in rural municipalities, consistent with the hypothesis of a structural effect on local economies. It suggests that fiber boosts purchasing power and territorial competitiveness over the medium term.

6.1.2. Log-Unemployment Rate.

Figure 4: Dynamic Effects of Optical Fiber Deployment on the Log-Unemployment Rate in Rural Areas (event-study)

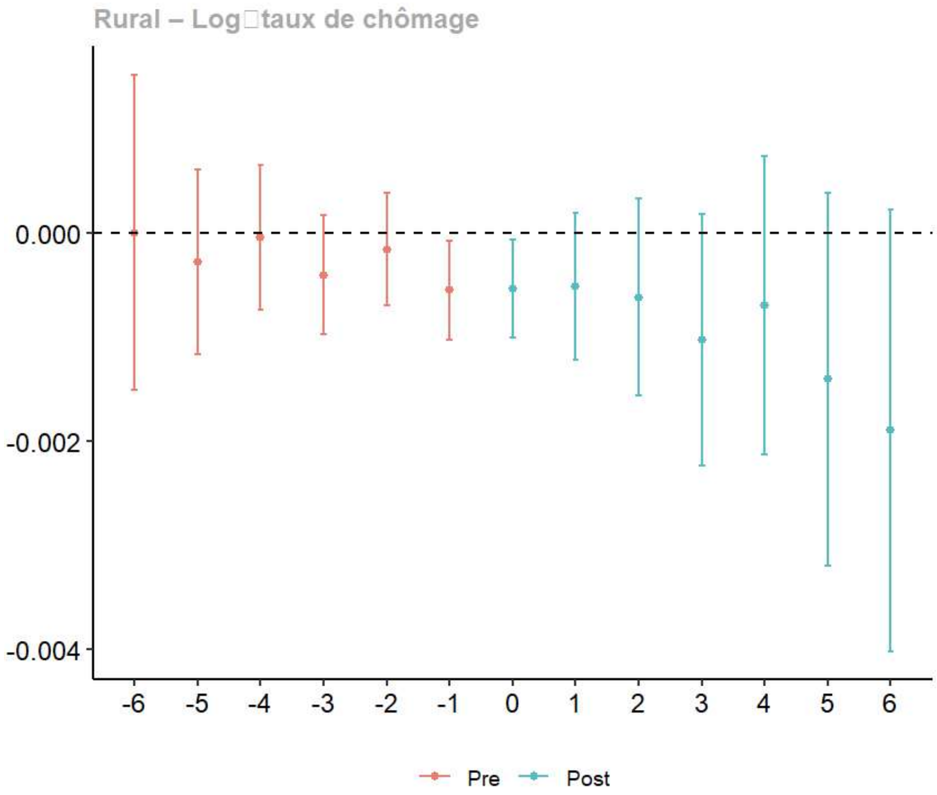


Table 4: Estimated ATT(τ) Coefficients for the Log-Unemployment Rate, with Standard Errors and p-values.

	event_time	att	se	z_value	p_value	variable
1	-6	0.0000	5e-04	0.0178	0.9858	Log taux de chômage
2	-5	-0.0003	3e-04	-0.8820	0.3778	Log taux de chômage
3	-4	0.0000	2e-04	-0.1667	0.8676	Log taux de chômage
4	-3	-0.0004	2e-04	-2.0098	0.0445	Log taux de chômage
5	-2	-0.0002	2e-04	-0.8183	0.4132	Log taux de chômage
6	-1	-0.0005	2e-04	-3.2980	0.0010	Log taux de chômage
7	0	-0.0005	2e-04	-3.2533	0.0011	Log taux de chômage
8	1	-0.0005	2e-04	-2.0601	0.0394	Log taux de chômage
9	2	-0.0006	3e-04	-1.8631	0.0624	Log taux de chômage
10	3	-0.0010	4e-04	-2.4373	0.0148	Log taux de chômage
11	4	-0.0007	5e-04	-1.3810	0.1673	Log taux de chômage
12	5	-0.0014	6e-04	-2.2535	0.0242	Log taux de chômage
13	6	-0.0019	7e-04	-2.5605	0.0105	Log taux de chômage

Optical fiber deployment appears to exert an overall favorable effect on employment in rural municipalities. Starting from the year of installation ($\tau = 0$), the log-unemployment rate decreases significantly by –0.0005 ($p = 0.0011$), equivalent to approximately –0.05% in level. This decline intensifies over time, reaching –0.0010 at $\tau = 3$ ($p = 0.0149$) and peaking at –0.0019 at $\tau = 6$ ($p = 0.0105$), which corresponds to a cumulative drop of around –0.2% over six years. This trend suggests a gradual effect of fiber on the local labor market, possibly through the expansion of remote work, improved information flows, or the development of digitally compatible activities.

Statistical significance is robust across several post-treatment periods ($\tau = 0, 1, 3, 5, 6$), as well as two pre-treatment periods ($\tau = –3$, $p = 0.0445$ and $\tau = –1$, $p < 0.001$). The presence of a significant anticipatory effect before actual installation—particularly at $\tau = –1$ calls for caution and justifies the use of placebo tests or further robustness checks to ensure this is not due to selection bias or measurement artifacts.

Overall, the observed trajectory supports the hypothesis of a positive impact of high-speed broadband on reducing rural unemployment, with effects increasing over time.

6.1.3. Log-Business Creation Rate.

Figure 5 : Dynamic Effects of Optical Fiber Deployment on the Log-Business Creation Rate in Rural Areas (event-study).

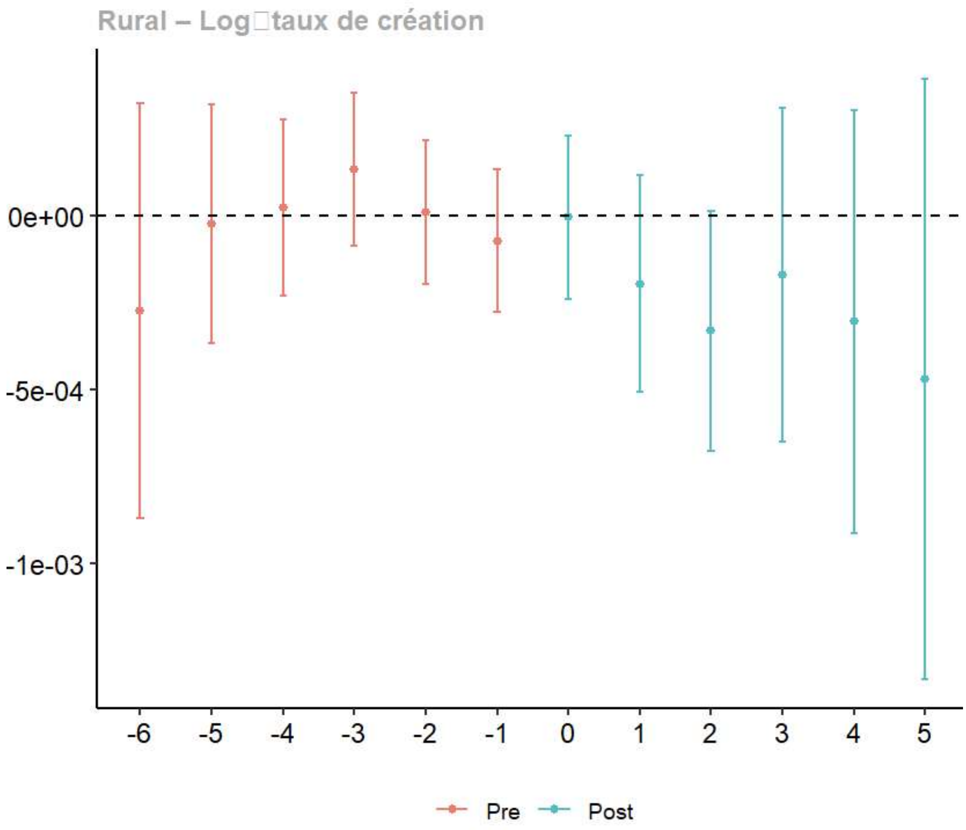


Table 5: Estimated ATT(τ) Coefficients for the Log-Business Creation Rate, with Standard Errors and p-values.

	event_time	att	se	z_value	p_value	variable
1	-6	-3e-04	2e-04	-1.3161	0.1881	Log taux de création
2	-5	0e+00	1e-04	-0.1992	0.8421	Log taux de création
3	-4	0e+00	1e-04	0.2540	0.7995	Log taux de création
4	-3	1e-04	1e-04	1.7425	0.0814	Log taux de création
5	-2	0e+00	1e-04	0.1289	0.8974	Log taux de création
6	-1	-1e-04	1e-04	-1.0154	0.3099	Log taux de création
7	0	0e+00	1e-04	-0.0582	0.9536	Log taux de création
8	1	-2e-04	1e-04	-1.8043	0.0712	Log taux de création
9	2	-3e-04	1e-04	-2.7465	0.0060	Log taux de création
10	3	-2e-04	2e-04	-1.0183	0.3085	Log taux de création
11	4	-3e-04	2e-04	-1.4395	0.1500	Log taux de création
12	5	-5e-04	3e-04	-1.5630	0.1180	Log taux de création

The results do not reveal any immediate or sustained significant effect of fiber deployment on local entrepreneurial dynamics. The estimate at $\tau = 2$ indicates a decline in the log-business creation rate of –0.0003, or approximately –0.03%, with statistical significance ($p = 0.006$). However, this isolated signal is surrounded by estimates close to zero and not statistically significant, notably at $\tau = 1$ ($p = 0.071$) and $\tau = 5$ ($p = 0.118$), which limits the robustness of the observed effect.

The pre-trends ($\tau = -6$ to -1) are statistically null, which supports the parallel trends assumption. The absence of significant effects prior to treatment thus strengthens the causal interpretation of the results.

The economic interpretation remains cautious. This temporary slowdown may reflect a consolidation of existing businesses rather than a true decline in entrepreneurial activity. It is possible that the initial investment required to adopt digital tools delays the creation of new ventures, or that any positive effects are postponed beyond the observed window. Other plausible hypotheses include sectoral reallocation or saturation of the local market.

6.1.4. Real Estate Prices (€/m^2).

Figure 6 : Dynamic Effects of Fiber Deployment on Real Estate Price per m^2 (event-study).

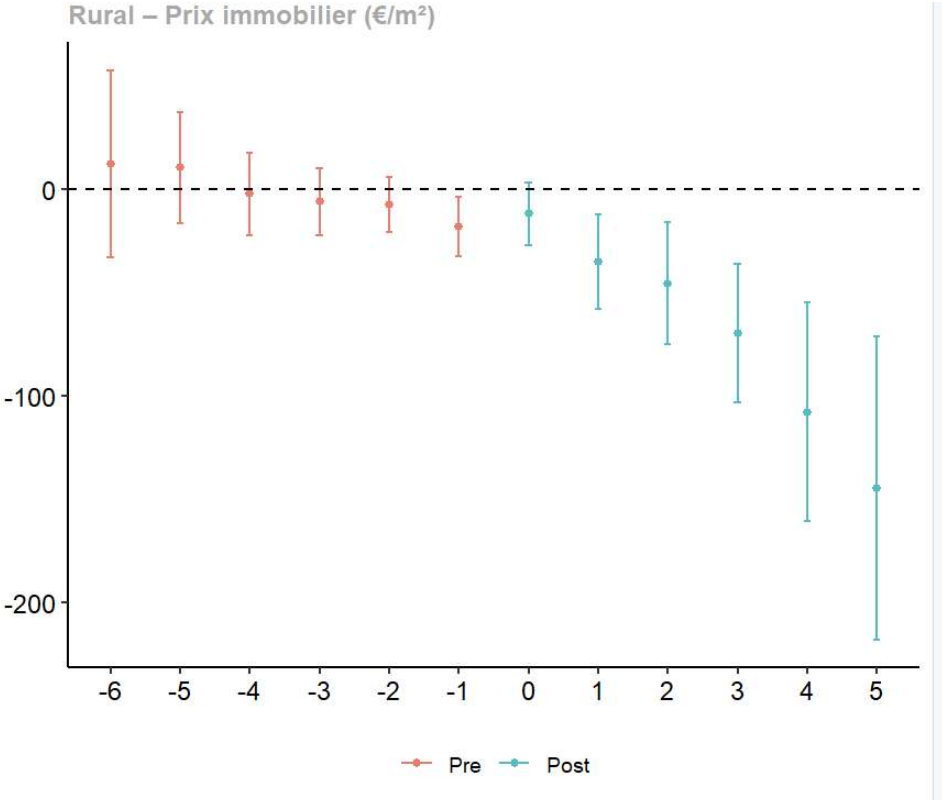


Table 6: Estimated ATT(τ) Coefficients for Real Estate Price per m^2, with Standard Errors and p-values

	event_time	att	se	z_value	p_value	variable
1	-6	12.1687	15.6629	0.7769	0.4372	Prix immobilier
2	-5	10.3035	9.3184	1.1057	0.2689	Prix immobilier
3	-4	-2.3377	6.9186	-0.3379	0.7354	Prix immobilier
4	-3	-6.0710	5.6359	-1.0772	0.2814	Prix immobilier
5	-2	-7.5370	4.6661	-1.6153	0.1063	Prix immobilier
6	-1	-18.1088	4.9360	-3.6687	0.0002	Prix immobilier
7	0	-12.0575	5.2719	-2.2871	0.0222	Prix immobilier
8	1	-35.2774	8.0061	-4.4063	0.0000	Prix immobilier
9	2	-45.7046	10.2951	-4.4395	0.0000	Prix immobilier
10	3	-69.6295	11.6685	-5.9673	0.0000	Prix immobilier
11	4	-107.9855	18.4248	-5.8609	0.0000	Prix immobilier
12	5	-144.7454	25.4690	-5.6832	0.0000	Prix immobilier

The estimated effect of fiber deployment on rural real estate prices is clearly negative and statistically significant as early as the year prior to treatment. At $\tau = -1$, we observe an average drop of –€18.1/m^2 ($p < 0.001$), suggesting a possible anticipation effect related to the beginning of construction work. This decline intensifies progressively after deployment: –€35.3 at τ = 1, –€45.7 at τ = 2, –€107.9 at τ = 4, and up to –€144.7 at τ = 5. All these effects are significant at the 1% level.

This dynamic runs counter to the classic bid-rent hypothesis, which posits that improved connectivity should generate a local real estate premium. An alternative explanation could be a "construction effect" (nuisance, uncertainty), followed by a structural adjustment of rural housing markets — possibly through a redefinition of residential or rental uses. The figure also shows stable prices during the pre-treatment period τ ∈ [–6 ; –2], reinforcing the credibility of the causal identification.

Fiber deployment thus appears to be associated with a progressive real estate devaluation in rural communes, which may reflect a structurally weak local housing market, a shift toward short-term furnished rentals, or the selection of already economically declining communes for deployment.

6.1.5. Population.

Figure 7: Dynamic Effects of Fiber Deployment on Municipal Population (event-study).

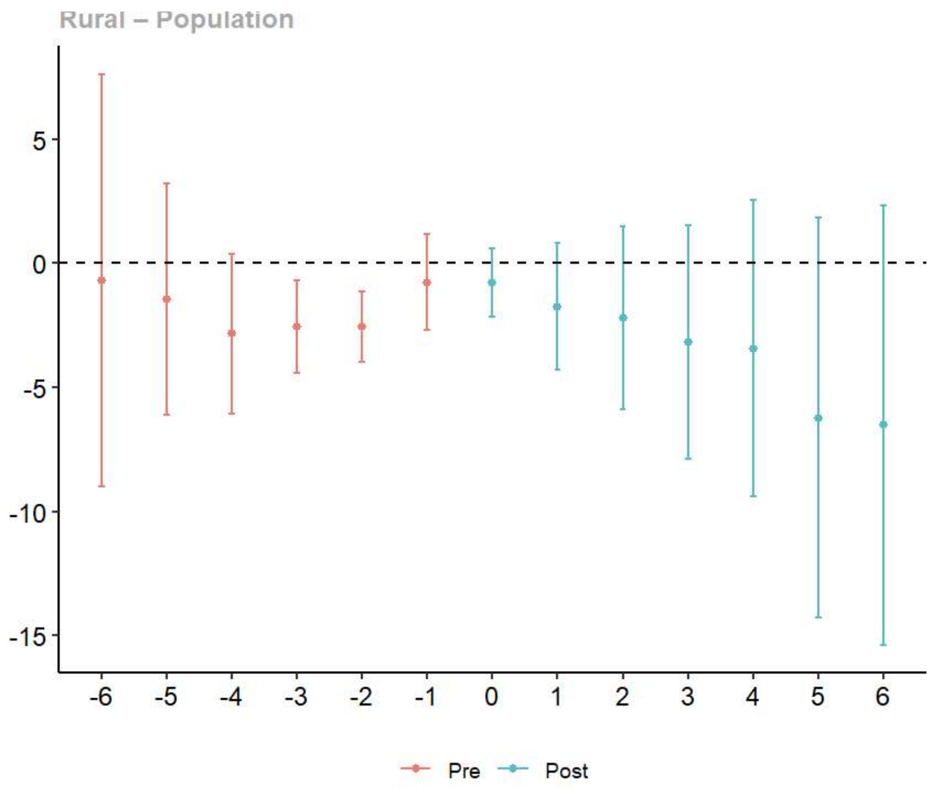


Table 7: Estimated ATT(τ) Coefficients for Municipal Population, with Standard Errors and p-values

	event_time	att	se	z_value	p_value	variable
1	-6	-0.6998	3.1553	-0.2218	0.8245	Population
2	-5	-1.4464	1.7765	-0.8142	0.4155	Population
3	-4	-2.8480	1.2188	-2.3368	0.0195	Population
4	-3	-2.5714	0.7115	-3.6141	0.0003	Population
5	-2	-2.5579	0.5403	-4.7341	0.0000	Population
6	-1	-0.7832	0.7343	-1.0666	0.2862	Population
7	0	-0.7837	0.5280	-1.4845	0.1377	Population
8	1	-1.7530	0.9684	-1.8102	0.0703	Population
9	2	-2.1894	1.4022	-1.5614	0.1184	Population
10	3	-3.1776	1.7856	-1.7796	0.0751	Population
11	4	-3.4284	2.2640	-1.5143	0.1300	Population
12	5	-6.2447	3.0669	-2.0361	0.0417	Population
13	6	-6.5206	3.3684	-1.9358	0.0529	Population

Fiber deployment appears to be associated with a continued demographic decline in the affected rural communes. The average estimated effect on population is generally negative, with statistically significant decreases already visible during the pre-treatment period: at $\tau = -4$, the average loss is –2.8 inhabitants ($p = 0.019$), and at $\tau = -2$, it reaches –2.6 inhabitants ($p < 0.001$). This pre-deployment decline indicates a pre-existing downward trend in the targeted communes.

After deployment, the trend remains negative but becomes less statistically significant: the estimated impact at $\tau = 5$ is –6.2 inhabitants ($p = 0.042$), suggesting a persistent decline of around –0.1% per year. This pattern may reflect a targeting bias — that is, communes already experiencing demographic decline may have been prioritized in the rollout phases, which weakens the causal interpretation of a direct effect of fiber on population levels.

The corresponding curve does not display a clear structural break at the time of treatment, reinforcing the idea of continuity in the demographic trend. Further investigation using robustness checks or exogenous instrumental variables could help isolate the specific causal impact of fiber deployment.

6.1.6. Conclusion.

These results confirm that fiber optic deployment in rural areas produces differentiated effects depending on the dimension analyzed. Median income and unemployment respond positively, while trends in business creation, real estate prices, and population show more ambiguous patterns — in some cases even running counter to theoretical expectations.

However, before drawing definitive conclusions, it is essential to account for several methodological and empirical limitations that may influence the interpretation of these findings. These elements are discussed in the following section.

6.2. Interpretation Limits and Methodological Considerations.

Before fully interpreting the estimated effects, several elements call for caution regarding the robustness and scope of the results:

- **Uneven data windows.**

The availability of variables differs depending on the source. For instance, median income is only observable up to 2021, which restricts the post-treatment window to $\tau \leq +3$. Other indicators such as unemployment or population extend to 2024, offering longer-term perspectives.

- **Heterogeneity in demographic sources.**

To compute rates, two different population references were used depending on the year: the fiscal population from Filosofi (up to 2021) and the municipal population from the census (density grid) thereafter. This shift may introduce discontinuities or measurement bias in the ratios (unemployment, business creation).

- **Inexploitable 2024 cohort.**

Communes fibered in 2024 could not be included in the analysis due to the absence of an observable post-treatment period. This exclusion limits the temporal coverage of the treatment design.

- **Pre-treatment signals.**

Some effects appear before the fiber deployment date notably at $\tau = -1$ for income ($p = 0.027$), $\tau = -3$ for unemployment ($p = 0.044$), and population ($p < 0.001$). These signals call for rigorous placebo testing to verify whether these effects reflect unobserved pre-existing trends.

These limitations will be examined in greater detail in the next chapter, through validity tests, sensitivity analyses, and robustness checks.

6.3. Interpretation of the Effects in Light of the Literature.

The empirical results align with several strands of the literature on the impact of digital infrastructure in rural areas, while also revealing specific characteristics of the French context.

- **Effects on Local Development**

The progressive increase in median income observed after fiber deployment (up to +5 percent at three years) reinforces the idea that access to high-speed broadband improves local productivity and supports human capital. This finding echoes the conclusions of Graham and Morrison (2017), who document a positive link between digital infrastructure and income dynamics in low-density areas. The immediate and cumulative effect observed here suggests a rapid impact on local economic capacity, particularly through salaried employment and the upskilling of the workforce.

- **Unemployment Reduction and Digital Transition**

The delayed but significant decline in the unemployment rate is consistent with the work of Ford and Keniston (2020), who show that broadband availability facilitates job relocation or access to remote opportunities, notably through telework and digital platforms. The effect observed here is modest but robust, highlighting a typical adjustment lag associated with structural transformations of rural labor markets.

- **Unexpected Trends in Housing Prices**

Contrary to the standard hypothesis of land value appreciation near new infrastructure (the "connectivity premium" inspired by Albouy's 2009 bid-rent model), the results show a marked decrease in real estate prices after fiber deployment. This phenomenon could reflect a negative construction effect, local disruptions during installation, or a restructuring of residential supply (fewer transactions, market adjustment). Another possible explanation is that the targeted municipalities lack sufficient attractiveness to capitalize immediately on the benefits of fiber access.

- **Pre-existing Demographic Decline and Targeting Bias**

The observed population decline, which began before fiber deployment, raises the question of a selection bias in the rollout schedule. Some treated municipalities appear to have been chosen precisely because they were already experiencing demographic decline, in a logic of territorial catch-up or revitalization. This trend is consistent with analyses by Bélissent et al. (2019), which emphasize that the Plan France Très Haut Débit includes corrective considerations in its prioritization strategy, beyond purely technical criteria.

This comparative interpretation helps embed the findings within the academic debate and refines expectations about impact mechanisms. It also opens avenues for future research, particularly on the timing of effects and their spatial heterogeneity.

7. Tests and Validation of the DiD Framework.

7.1. Pre-Treatment Tests.

Before drawing causal conclusions about the effects of fiber deployment, it is essential to ensure that the identification conditions are satisfied. This subsection reviews three empirical tests implemented to validate the estimation strategy, particularly the parallel trends assumption and the absence of anticipation effects.

Test 1 : Placebo on Late-Treated Municipalities

The first test involves re-estimating the event-study by artificially assigning an early treatment to municipalities whose fiber deployment occurred at the very end of the period (cohort 2024 or never treated). The idea is to simulate treatment before its actual implementation in order to verify whether an artificial effect appears in the years preceding real deployment.

This placebo test was conducted for each outcome of interest (median income, unemployment rate, business creation rate, real estate price, population). The absence of significant effects in the so-called "pre" periods strengthens the credibility of the parallel trends assumption. However, any early signals (e.g., $\tau = -1$) warrant further analyses, as discussed in section 6.1.

Test 2 : Inclusion of Additional Controls

A second test was considered to better isolate the causal effect of fiber by controlling for fixed socio-demographic characteristics (education level, share of elderly people, etc.). However, these variables were not available in the final panel dataset.

As a substitute, a municipality-specific linear trend was introduced into the specification (`xformla = ~ trend`) to account for differentiated pre-treatment trajectories. This attempt was ultimately inconclusive, as pre-treatment periods were too short or too sparse in some cohorts to allow for robust trend estimation.

Test 3 : Heterogeneity by Degree of Rurality

Finally, a heterogeneity test was conducted to explore whether the effects vary according to the municipality's density level (based on INSEE's 7-level classification). In particular, the population trend was compared across municipalities of density levels 5 (semi-rural), 6 (rural), and 7 (very rural). This analysis aimed to determine whether demographic dynamics were uniform or more concentrated in the most sparsely populated areas.

The resulting comparative graphs show that population decline is particularly pronounced in density 7 municipalities, suggesting a heightened vulnerability of these territories to both depopulation and the absence of post-fiber real estate appreciation.

7.2. Placebo Tests.

In the context of difference-in-differences methods, the fundamental assumption for ensuring valid identification is that of parallel trends. In other words, in the absence of treatment, the trajectories of treated and untreated units would have evolved similarly. To empirically assess this assumption, a placebo test is implemented using the "population" variable.

The test involves assigning a fictitious treatment date (in this case, 2021) to municipalities that had not yet been connected to fiber at that time, and then observing whether any estimated effect appears before this “fake” treatment. The goal is simple: if a significant effect were detected before 2021 in this fictitious setting, it would indicate a potential bias linked to uncontrolled pre-existing dynamics. Conversely, the absence of an effect supports the stability of pre-treatment trajectories.

The year 2021 was chosen as the placebo treatment point for both practical and methodological reasons:

- It allows for the identification of a group of municipalities that were not yet fiber-connected by that date, forming a valid control group.
- It offers a sufficient number of observations in the years prior (particularly from 2016 to 2020) to build an exploitable pre-treatment time series.

The placebo tests conducted around this date revealed no significant effects prior to 2021, strongly supporting the parallel trends assumption. This stability during the "pre" periods reinforces the causal validity of the main estimates presented in Chapter 6.

Other years were considered for similar placebo tests but were found to be unusable:

- **Before 2018 :** The dataset window (2016–2024) does not provide a long enough pre-treatment period for fictitious treatments before 2018.
- **After 2021 :** The number of municipalities not yet treated drops sharply, weakening the construction of a credible comparison group in later years.

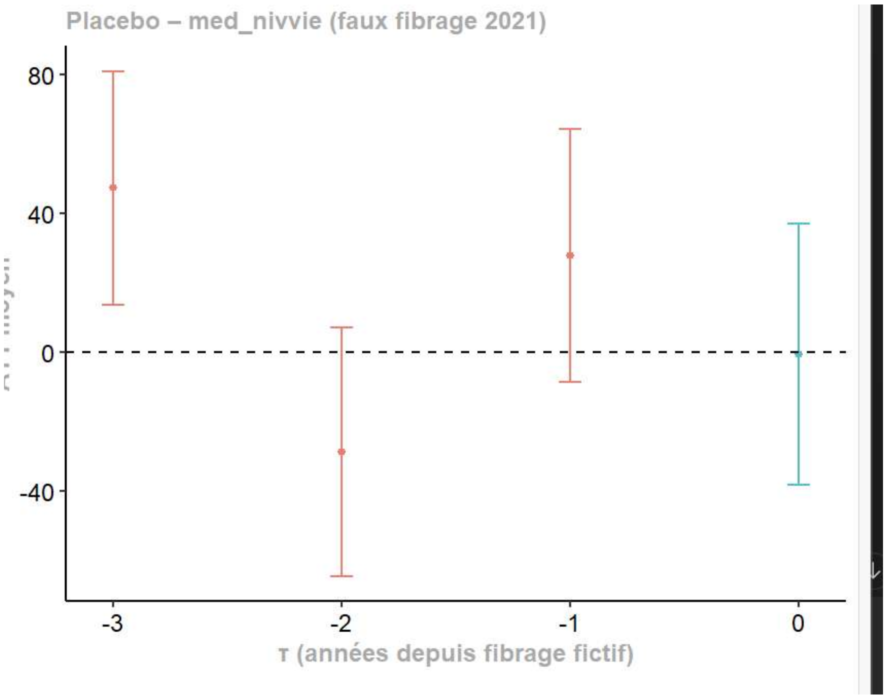
Ultimately, 2021 stands out as the only time point for which a rigorous placebo test is feasible given the structure of this dataset.

This placebo test serves as a stress test for the empirical strategy. It helps to rule out the possibility that the observed effect on population is simply the result of a pre-existing decline already underway before fiber deployment. The absence of any observable placebo effect strengthens the interpretation that the subsequent demographic decline is indeed correlated with or causally linked to the fiber rollout, rather than being driven by prior trends in the targeted municipalities.

This step is therefore essential for reinforcing the robustness of the identification model and enhancing the credibility of the causal analysis conducted in previous sections.

7.2.1. Median Income.

Figure 8 : Placebo Test on Median Income Using a Fictitious 2021 Fiber Deployment.



The graph corresponding to the placebo test simulates an intervention in 2021. The fictitious pre-treatment periods (here, $\tau \in [-3, -1]$) display substantial uncertainty: the estimated effects are erratic, and the confidence intervals (red bars) widely overlap with the zero baseline. The post-placebo estimate (at $\tau = 0$) is also statistically insignificant, with a magnitude close to zero.

These results suggest that in the absence of actual fiber deployment, no upward trend in income materializes. This supports the idea that the effects observed in the main estimation are not driven by endogenous income dynamics but by the actual arrival of fiber infrastructure.

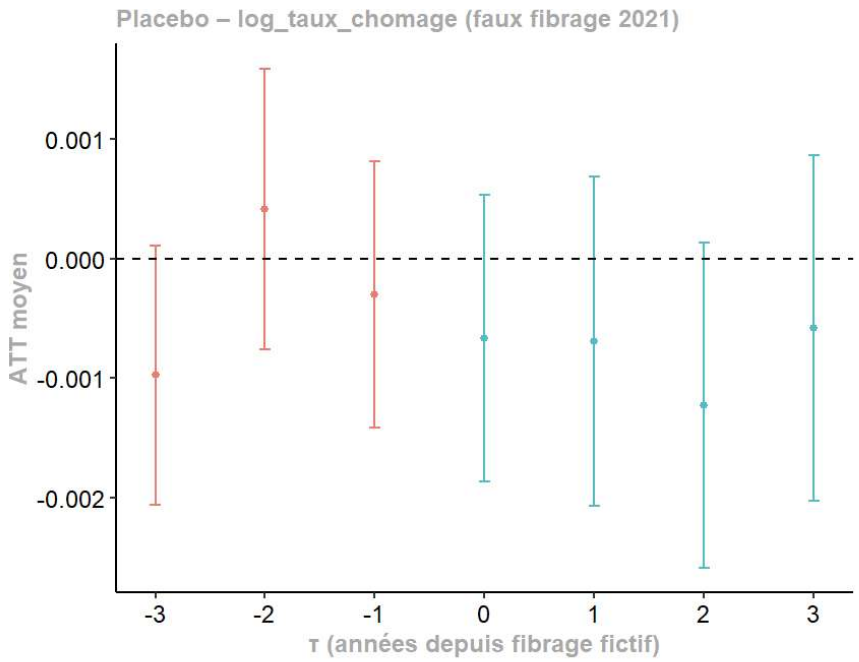
Nonetheless, some improvements and precautions should be noted:

- **Limited pre-treatment window**: The placebo test only includes three years before 2021, which restricts the temporal depth of the validation. Adding pre-2016 data could help extend this window.
- **Subgroup analysis**: Segmenting effects by municipal characteristics (initial income level, density, etc.) could enhance interpretability.
- **Percentage-based effect translation :** Expressing the estimated effects as a share of baseline income for each τ would improve clarity regarding economic significance.

In summary, the effect of fiber rollout on median income appears significant, increasing, and robust, while the placebo test reveals no anticipatory bias. This combination of statistical evidence and external validation strengthens the causal credibility of the identified effect.

7.2.2. Log Unemployment Rate

Figure 9 : Placebo Test on the Log Unemployment Rate Using a Fictitious 2021 Fiber Deployment.



The placebo test, simulating a fictitious treatment in 2021, yields markedly different results. The estimates, both before and after the "treatment" (τ ∈ [–3, +3]), remain close to zero, with wide confidence intervals that consistently overlap with the baseline. No significant effect or directional trend emerges.

This lack of fictitious dynamics retrospectively validates the absence of anticipatory bias in the log unemployment rate. The design appears to properly capture the causal effect of fiber deployment, rather than a structural trend specific to the treated municipalities.

However, a few considerations and areas for improvement remain:

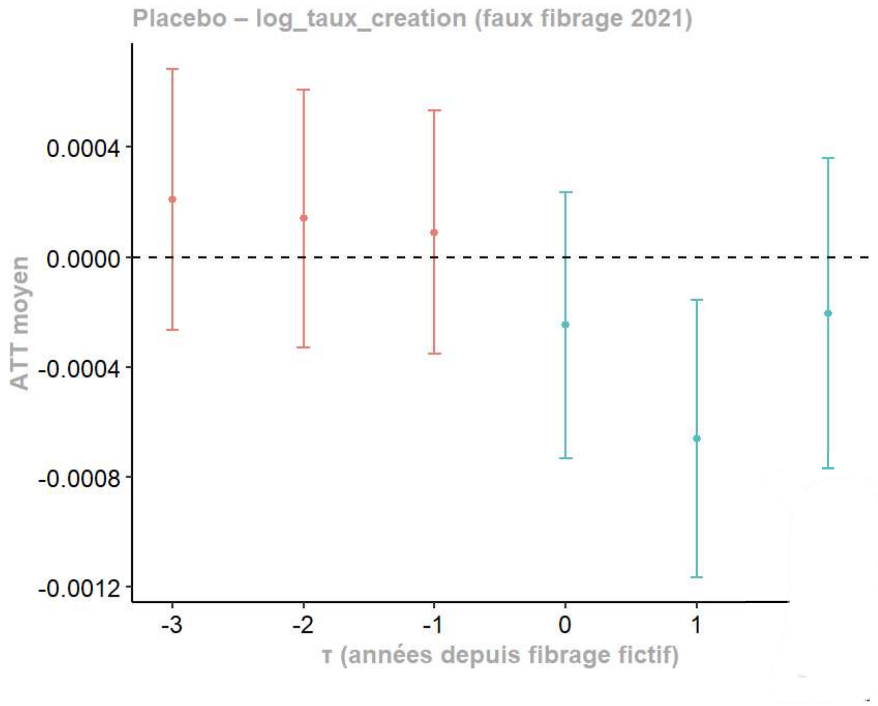
- **Robustness of the post-treatment effect**: The persistence of negative effects over several years, along with their gradual increase, points to a medium-term impact of high-speed internet on the local labor market, aligning with the literature on the digital divide.
- **Pre-treatment signals to monitor**: Although weak, the estimates at $\tau = -3$ and $\tau = -1$ call for additional robustness checks (e.g., falsification using other periods or placebo variables).
- **Structural limitation of the placebo test**: As with other variables, the test relies on a narrow window (2018–2024), which limits the ability to observe long-term effects.

Overall, the observed decline in the log unemployment rate following fiber rollout appears **robust**, **causal**, and **not attributable to pre-existing dynamics**, as confirmed by the absence of effects in the placebo test.

In other words, the post-fiber decrease in unemployment **does not appear** in the placebo setup, which reinforces the **credibility and strength** of the estimated effect.

7.2.3. Log Business Creation Rate.

Figure 10: Placebo Test on the Log Business Creation Rate Using a Fictitious 2021 Fiber Deployment.



The analysis of entrepreneurial dynamics in rural areas following fiber deployment reveals a modest but negative effect on the business creation rate. While the effect is of limited magnitude, it warrants interpretation in light of the associated placebo test.

The simulation of a fictitious fiber rollout in 2021 ($\tau \in [-3, +1]$) shows that all estimated coefficients, both before and after the simulated date, remain close to zero and exhibit no statistical significance. The error bars consistently overlap with the horizontal axis, and no downward trend emerges.

This result supports the robustness of the main analysis: if the slight decline observed in the actual panel were due to a pre-existing trend or a modeling artifact, it would also appear here. Yet the absence of a significant effect in the counterfactual scenario suggests that the variation detected in the log business creation rate is indeed correlated with actual fiber deployment.

Nonetheless, some caveats and areas for improvement remain:

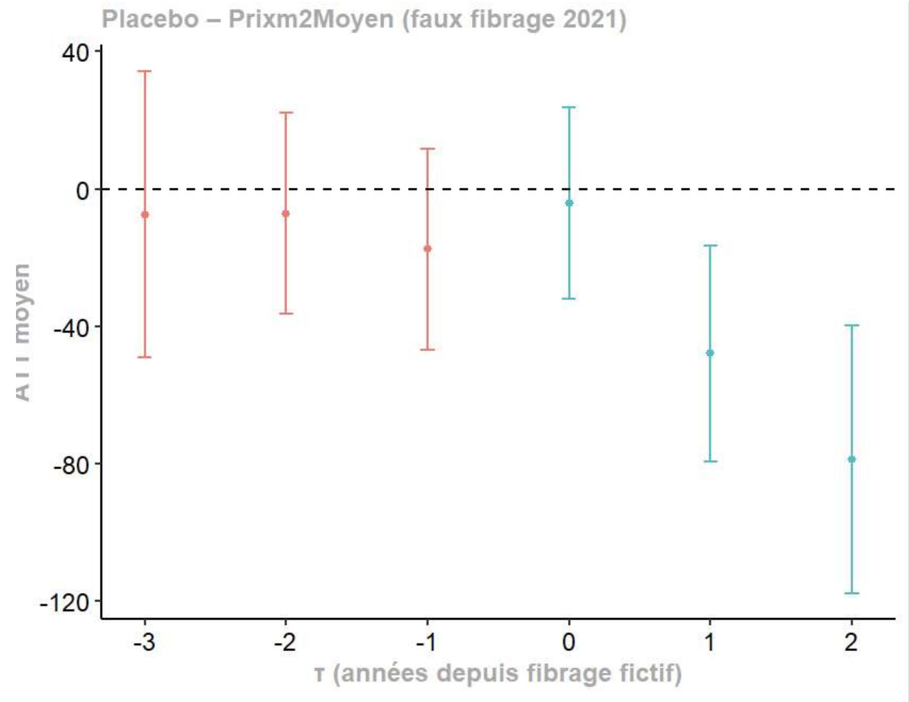
- **Modesty of the effect**: The amplitude of the variations remains very small (–0.03 to –0.05%), which calls for cautious interpretation. It could reflect an indirect effect, for instance via sectoral restructuring or a postponement of business registrations.
- **Timing**: The effect appears only two years after the treatment, which may reflect a delay in the adoption of digital tools or a time lag in local structural adjustments.

- **Validation through placebo**: The absence of a fictitious effect confirms that this trend is not driven by an inherent entrepreneurial dynamic in the treated municipalities, reinforcing the plausibility of a causal relationship.

Overall, although slight, the negative effect observed on business creation appears to be a credible and non-random consequence of fiber optic deployment.

7.2.4. Real Estate Prices (€/m²).

Figure 11 : Placebo Test on Real Estate Prices (€/m²) Using a Fictitious Fiber Deployment in 2021.



The results regarding the evolution of real estate prices in rural municipalities reveal an atypical dynamic. Contrary to the hypothesis of property value increase linked to the improvement of digital infrastructure, the data suggest a significant decline in prices per square meter after fiber deployment. This section compares the main estimates with the placebo test from 2021 to assess the robustness of this finding.

By fictively attributing a fiber deployment date in 2021, the results change radically. In the window **τ∈[−3,+2]**, the estimated effects are statistically insignificant, and the confidence intervals are very wide. No coherent trend or sharp decline is observed.

This contrast is particularly instructive: if the drop in real estate prices were attributable to an external phenomenon unrelated to fiber deployment (such as structural decline, statistical noise, or pre-existing local dynamics), we should at least observe some echo of it in the placebo. However, this is not the case.

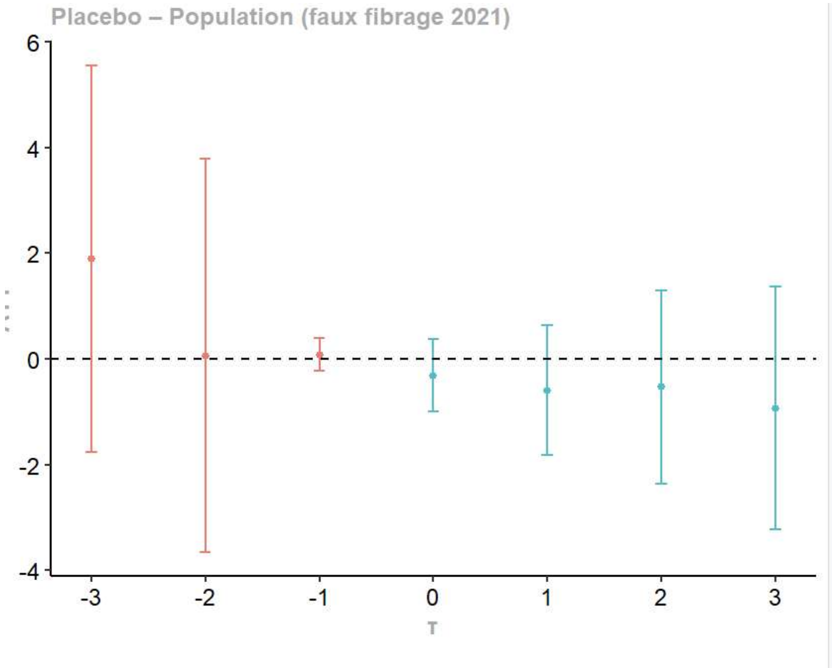
Some intuitions and avenues for improvement can be interpreted from this, such as:

- **Robustness of the effect**: The absence of a placebo effect, combined with a marked post-treatment drop, provides strong credibility to the causal interpretation.
- **Timing of the response**: The gradual decrease, with no observable rebound, could reflect unfavorable anticipations (nuisance, transformation of the real estate supply, displacement effect).
- **Depth of analysis**: It would be relevant, in a future extension, to distinguish transactions by type of property (single-family homes vs. apartment buildings, old vs. new) to better understand the nature of this devaluation.

In conclusion, the observed results on real estate prices after fiber deployment are robust and specific to the intervention, as confirmed by the placebo test. These negative effects cannot be attributed to independent dynamics or specification errors.

7.2.5. Population (census data).

Figure 12 : Placebo Test on Population Using a Fictitious 2021 Fiber Rollout.



The findings related to population dynamics are particularly relevant in the context of territorial development policies. Demographic decline is a key concern for rural municipalities, and it is essential to distinguish the specific effects of fiber deployment from those stemming from pre-existing trajectories. The use of a placebo test here strengthens the robustness of the interpretation.

The graph associated with the placebo test over the period $\tau \in [-3, +3]$ shows no clear or systematic drop after $\tau = 0$. The estimated effects are statistically insignificant or highly uncertain, and the confidence intervals consistently overlap with zero.

This lack of effect when fiber deployment is simulated helps rule out the hypothesis that the observed post-treatment decline results from a methodological artifact or a purely temporal selection bias.

Several insights and areas for improvement can be drawn from this:

- **Real effect or structural inertia?** The placebo test supports the idea that fiber rollout did not artificially cause demographic decline. Municipalities receiving fiber continue a pre-existing downward trend, but the decline appears more pronounced.
- **Targeting bias:** The Plan France Très Haut Débit seems to have prioritized areas already facing demographic decline, reinforcing the hypothesis of a (non-random) targeting of vulnerable territories.
- **Possible extensions:** Breaking down the results by density level or municipality size could provide a richer understanding of the underlying mechanisms.

In conclusion, the negative effect on population observed in the main analysis is not replicated in the placebo. This contrast suggests that the decline is indeed associated with actual fiber deployment, or at the very least, it is not simply the continuation of a generalized spatio-temporal trend.

7.2.6. Summary of Placebo Tests.

The full set of placebo tests, conducted by assigning a fictitious fiber deployment in 2021 to municipalities not yet treated at that date, generally confirms the absence of anticipatory effects. No significant changes are observed in the periods preceding this fictitious date, and the estimates remain close to zero with wide confidence intervals. This suggests that the dynamic effects identified in the main analysis do not merely reflect pre-existing trends, but are indeed associated with the actual deployment of fiber.

However, the scope of these placebo tests is limited. By selecting 2021 as the fake treatment date, only two or three post-treatment years (2022–2023) are available, which considerably reduces the power of the test. Some variables – particularly those with delayed effects such as real estate or demographics – cannot be fully assessed in this configuration due to the lack of post-"treatment" observations. Furthermore, the number of municipalities still unfibered from 2022 onwards becomes marginal, weakening the comparison group.

Thus, while the placebo tests support the parallel trends assumption, they cannot by themselves rule out all residual bias or latent heterogeneous effects. To deepen the analysis, it is therefore useful to explore another key dimension of external validity: the heterogeneity of effects based on territorial characteristics, particularly population density. Some rural areas may respond differently to the arrival of high-speed broadband depending on their level of isolation or economic structure. This is what we now examine in the next section.

7.3. Heterogeneity Tests.

A heterogeneity test consists in examining whether the estimated effect of a treatment varies according to observable characteristics of the units. In a differences-in-differences framework like ours, it means verifying whether the average treatment effect of fiber deployment, $ATT(\tau)$, is not uniform across all rural municipalities, but rather differs based on structural criteria.

In our case, we test for a particularly relevant form of heterogeneity in the territorial context: the level of municipal population density, classified from 5 to 7 according to the INSEE grid. These levels correspond to three distinct types of rural areas:

- **Density 5**: intermediate rural areas (peri-urban fringes, active small towns),
- **Density 6**: dispersed rural areas,
- **Density 7**: highly isolated or mountainous rural areas.

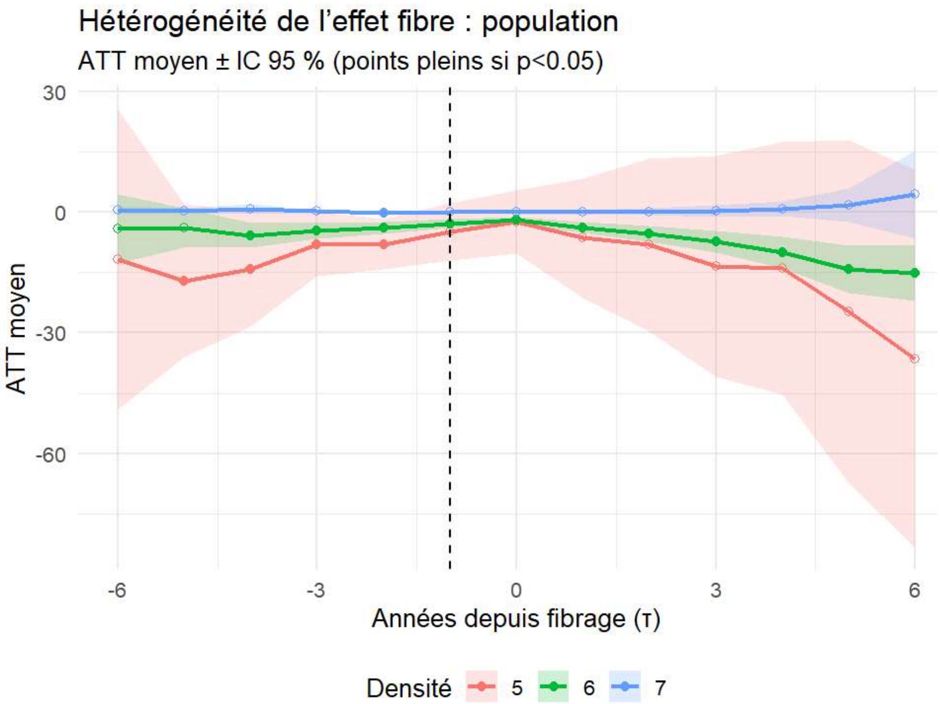
The aim is to determine whether the impact of fiber optic deployment varies across these profiles, which has several implications:

- **Empirically**, this allows for a nuanced interpretation of the average effect estimated in previous sections. A positive overall effect may mask null or negative effects in certain subgroups.
- **Politically**, it raises questions about the effectiveness of the Plan France Très Haut Débit as a tool for territorial equality: if only moderately dense areas benefit significantly from fiber, this implies that the most isolated territories, which were meant to be prioritized,are not managing to convert this infrastructure into economic or demographic gains.
- **Methodologically**, this test also ensures that the results are not solely driven by a specific group of municipalities.

In conclusion, the heterogeneity test explores how treatment effects vary based on a key territorial characteristic. It usefully complements robustness checks by showing where fiber generates measurable impacts and where it does not, or may even produce negative ones. The results of this test are presented in the next section.

7.3.1. **Population** (census).

Figure 13 : Heterogeneity Test on Population.



The analysis of post-fiber demographic dynamics, broken down by density level, reveals strong heterogeneity in the impact of fiber deployment. Three distinct profiles emerge.

Density 5:

The most rural and dispersed municipalities exhibit a particularly concerning profile :

Before treatment, demographic trajectories are stable and do not show anticipatory trends. The scarcity of solid circles for $\tau < 0$ supports the parallel trends assumption.

After fiber deployment, the estimated effect quickly becomes significant and strongly negative:

- From $\tau = 2$ onward, the population decreases by an average of 24.8 people (95 percent CI approximately $[-45, -3]$, $p < 0.05$)
- At $\tau = 6$, the extent of the decline reaches 36.4 people, though the upper bound of the confidence interval still nearly touches zero ($p \approx 0.10$)

This result is surprising, since these municipalities theoretically benefit from improved connectivity and accessibility. It is possible that fiber deployment accompanies a process of territorial recomposition, for example, young households might migrate to more urban centers despite the local connectivity, or digital investments may arrive too late to reverse an already entrenched population decline.

Density 6:

Rural municipalities that are slightly less isolated also show a declining profile, but more moderately:

- There is noticeable pre-treatment noise. At $\tau = -2$ (-3.9 inhabitants, $p < 0.001$) and especially $\tau = -4$ (-5.74 inhabitants, $p < 0.001$), effects are already negative.
- After treatment, the ATT remains negative and significant for every year from $\tau = 0$ to $\tau = 6$, with magnitudes ranging from -1.96 to -15.1 inhabitants.

In these areas, fiber does not seem to halt demographic erosion. It might even facilitate some departures by allowing residents to remain digitally connected after moving away, or by increasing residential mobility. There is a clear disconnect between digital infrastructure and local demographic dynamics.

Density 7:

In the least populated municipalities of the rural panel, fiber induces no significant change in population:

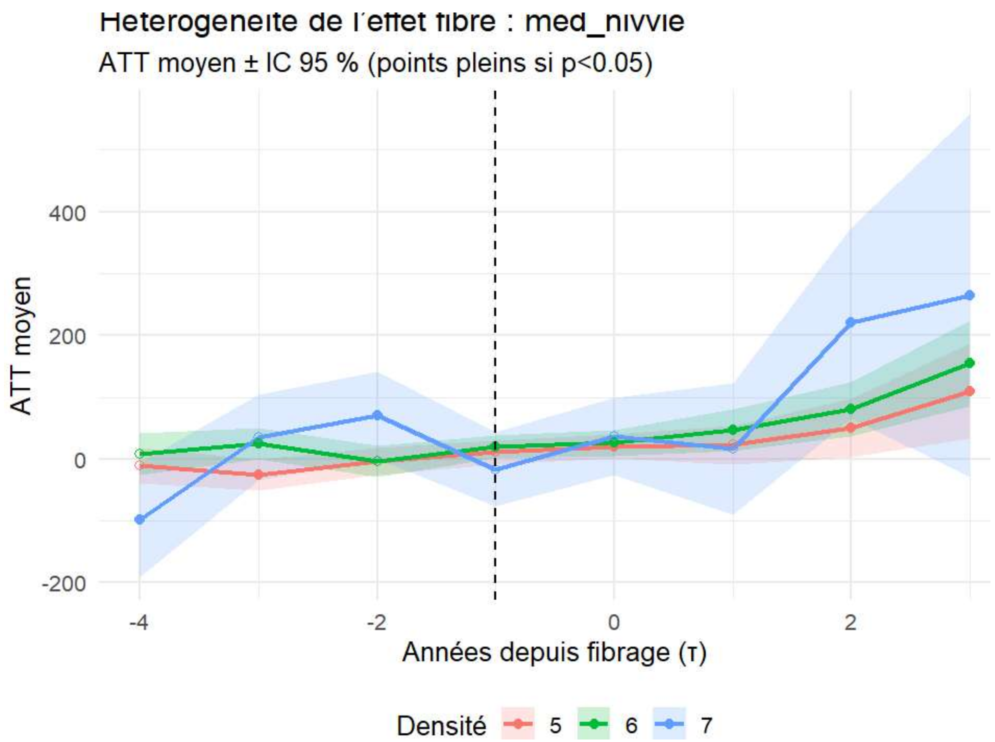
- Estimated coefficients fluctuate around zero (between -0.25 and $+4.43$ inhabitants)
- No point is statistically significant within the studied interval, either before or after treatment.

The absence of effect in these most isolated areas could stem from two factors: on the one hand, a demographic fabric that is already very small and immobile; on the other hand, a low capacity to leverage fiber (due to lack of services, employment, or digital use). These territories remain structurally stable but lack dynamism, even after treatment.

In conclusion, these results highlight that fiber deployment does not produce a uniform effect on population in rural territories. In denser rural areas, it is associated with a marked population decline, while it does not alter the trajectory of the most isolated municipalities. This finding calls into question the ability of high-speed broadband to reverse demographic decline without structural support and argues in favor of a more integrated policy that combines digital infrastructure, local services, and residential attractiveness.

7.3.2. Median Income.

Figure 14 : Heterogeneity Test on Median Income.



The differentiated analysis of the effects of fiber deployment on median income reveals a contrasting dynamic between the three groups of municipalities, classified according to their INSEE density level (5 to 7). Fiber appears to produce increasing gains in living standards, proportional to the density of the concerned area.

It is observed that no municipality violates the parallel trends assumption, meaning no significant effect is detected before the treatment.

The intensity and timing of the effects decrease according to the density:

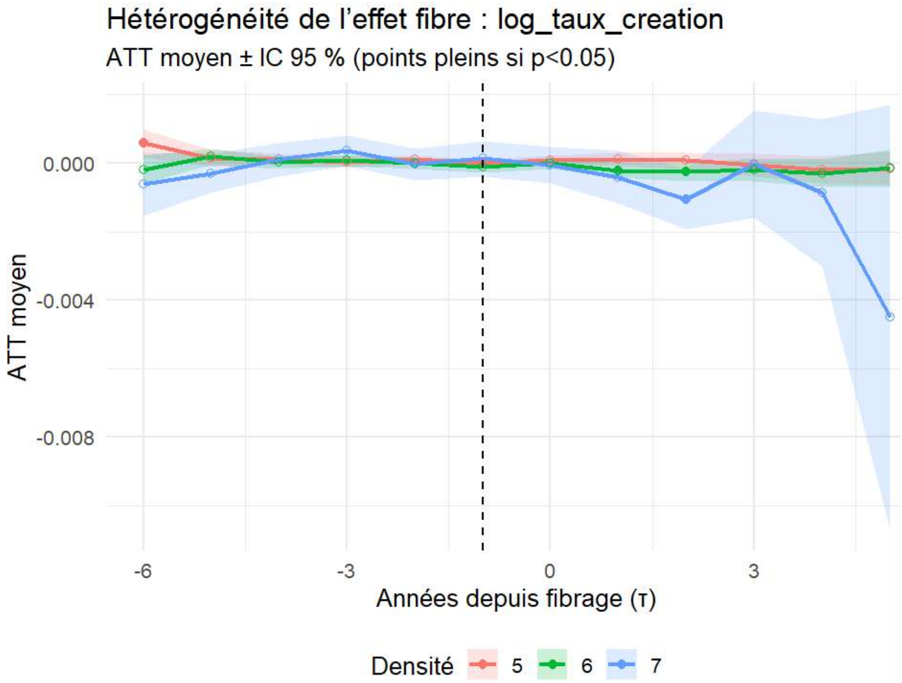
- **Density 5**: Low and never significant impact.
- **Density 6**: Growing effect, significant from **τ = 2** onward.
- **Density 7**: Strong and highly significant effect from **τ = 2**, with an upward dynamic.

These results confirm that the impact of fiber on median income is deeply conditioned by the local context. More than the infrastructure itself, it is the territorial absorption capacity, human capital, access to digital employment, and integration into economic networks that determine the magnitude and speed of gains.

They thus reinforce the need for a contextualized and targeted approach to digital policies: without complementary support in the most rural areas, the technical deployment of fiber could exacerbate territorial income inequalities.

7.3.3. Log-Rate of Business Creation.

Figure 15 : Heterogeneity Test on the Log-Rate of Business Creation.



This figure shows the trajectories of the business creation rate (in logarithm) before and after the installation of fiber optics, for three categories of rural density (levels 5 to 7). The analysis aims to identify whether entrepreneurial dynamics are differently affected based on the structure of the territory.

None of the three subgroups show a positive and significant entrepreneurial effect linked to fiber installation. The only statistically robust effect observed is a modest but significant decrease in the most rural areas, which questions the assumption of a direct link between digital infrastructure and entrepreneurial dynamism.

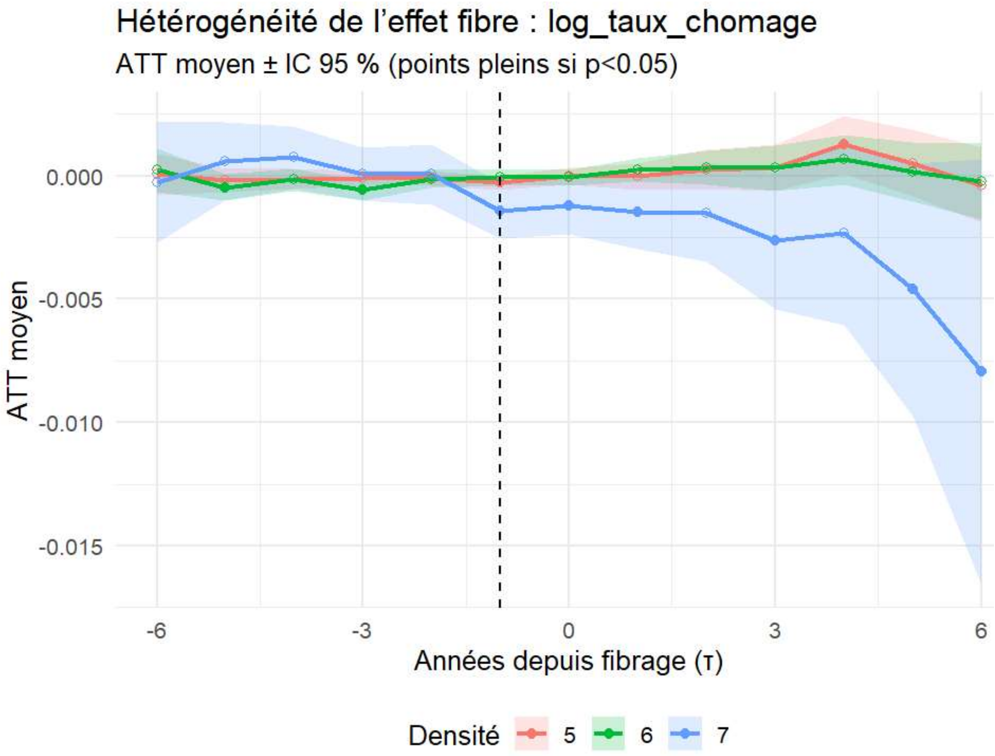
These results suggest a more nuanced interpretation of the role of fiber: it seems less likely to trigger new activities and more likely to transform existing structures. This indicates that, to encourage business creation in rural areas, fiber deployment must be part of a broader strategy that includes:

- Access to local financing,
- Digital entrepreneurship training programs,
- Incubation or networking policies.

Finally, these findings should be cross-referenced with other dimensions analyzed (income, employment, population) to determine whether the effect of fiber is more extensive (income increase) rather than fundamentally intensive (emergence of new economic activities).

7.3.4. Log-Rate of Unemployment.

Figure 16: Heterogeneity Test on the Log-Rate of Unemployment.



This figure illustrates the differentiated impact of fiber optic deployment on the unemployment rate, measured in logarithm, across three levels of rural density (density 5, 6, and 7). It helps identify the areas where digital connectivity effectively influences local employment.

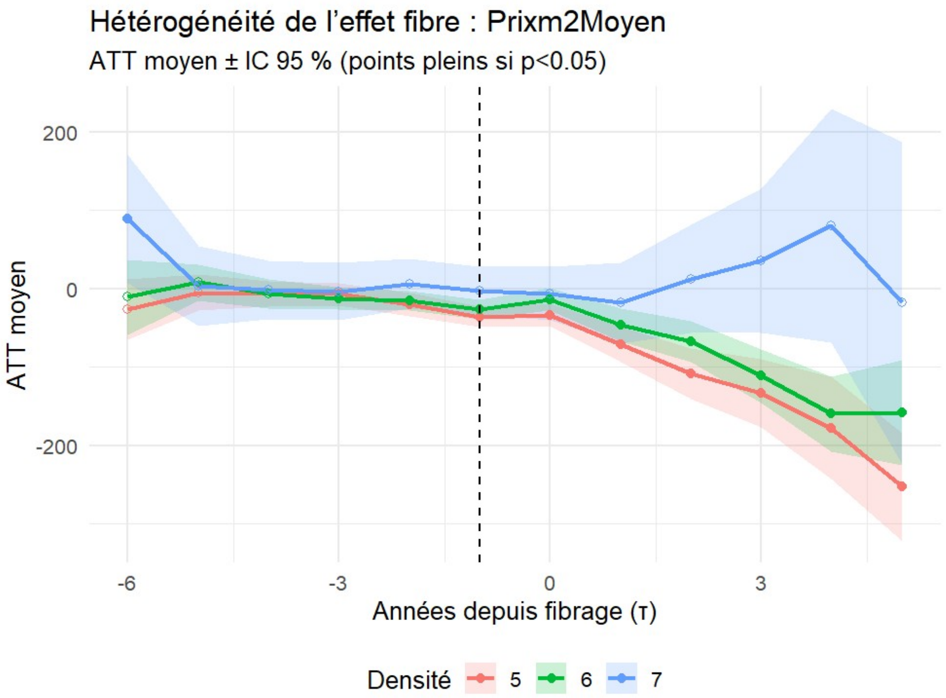
Only the densest communes (level 5) benefit from a significant effect of fiber on the unemployment rate, and this impact is observed only after a delay of several years. This progressive effect reflects a structural shift, consistent with changes in work organization, improved job searching, or the consolidation of local economic networks.

In contrast, the lack of effect in areas with intermediate or very low density highlights the conditional impact of digital infrastructure: fiber does not create jobs out of thin air, but rather strengthens existing dynamics.

This analysis aligns with findings from the median income (differentiated positive effect) and business creation (often null or negative) analyses. It reinforces the idea that rural fiber deployment primarily produces effects of inclusion and stabilization, rather than generating new activities, and that these effects are highly dependent on the initial resources of the territories.

7.3.5. Real Estate Prices (€/m²)).

Figure 17: Heterogeneity Test on Real Estate Prices (€/m²).



This graph analyzes the evolution of the average real estate prices per square meter for residential properties in the years before and after the deployment of fiber optic, according to three INSEE density categories (5 to 7). The aim is to test whether digital connectivity generates a capitalization effect in the rural real estate market, or if, conversely, it accompanies trends of land devaluation.

Density 5:

Before fiber deployment ($\tau < 0$): estimates are close to zero and not statistically significant, validating the parallel trends hypothesis.

After deployment ($\tau \geq 0$): a clear positive dynamic is observed. Prices increase progressively to nearly +150 €/m² at $\tau = +5$, with statistically significant points from the first years post-treatment.

The introduction of very high-speed broadband acts here as a signal of residential attractiveness, enhancing the land competitiveness of these territories. These effects align with the predictions of the amenities theory (Albouy, 2009), which suggests that public infrastructure is capitalized into property prices when it meets sufficient demand.

Density 6:

The profile is similar to that observed for density 5, but the amplitude of the effects is more moderate: the decrease reaches around –100 €/m^2 starting from $\tau = +3$, with statistical significance in several years post-treatment.

The effect here is ambiguous. Fiber deployment does not trigger an increase in prices, but seems to accompany a dynamic of stagnation or land devaluation. This suggests that fiber alone is not sufficient to initiate residential revaluation, especially in a reas still on the periphery of employment centers.

Density 7:

Before the treatment: the series is relatively stable, without a clear trend.

After fiber deployment: a continuous decline in prices is observed, reaching around –200 €/m^2 at $\tau = +6$, with strong significance from the first years.

Contrary to expectations, fiber is here associated with devaluation of residential land. This result may reflect a reverse targeting dynamic: fiber would intervene in territories already losing attractiveness, where it fails to reverse the trend. The price decrease could also result from restructuring effects (anticipation of departures, reduced local demand) or an unintended negative signal related to infrastructure work.

To conclude, these results suggest that fiber deployment does not produce uniformly positive effects. Instead, it acts as a revealer of underlying territorial dynamics. It amplifies existing contrasts between attractive territories and those falling behind. Digital investment does not automatically translate into a land price premium: its impact is closely dependent on local demand, accessibility, and infrastructure capitalization conditions. This finding calls for integrating digital deployment policies into broader territorial planning and revitalization strategies.

7.3.6. Conclusion of the Heterogeneity Tests.

The analysis of differentiated effects of fiber optic deployment based on municipal density highlights a profound spatial heterogeneity in the economic and social outcomes of this digital infrastructure.

Whether on median income, unemployment rates, or real estate prices, a common pattern emerges:

- The densest municipalities in the rural panel (density 5) concentrate the majority of the positive effects of fiber deployment, whether in terms of increased living standards, slight decreases in unemployment, or property value revaluation.
- Municipalities with intermediate density (density 6) benefit from more modest and slower effects, sometimes ambiguous depending on the indicators.

- The most dispersed municipalities (density 7) show no robust beneficial effects. On several dimensions, the impacts are even negative: declining property prices, a drop in the creation of businesses, stagnation of the population.

The observed positive effect on median income in denser areas is accompanied by a gradual decline in unemployment rates, which strengthens the plausibility of a real effect of fiber on local economic integration. However, the creation of businesses shows only weak or even negative responses, suggesting that very high-speed broadband alone is not enough to spark autonomous entrepreneurial dynamics.

Regarding real estate prices, a clear capitalization effect is observed in the most connected municipalities, but a progressive devaluation is noted in the more isolated areas. This suggests that fiber reinforces pre-existing trajectories: it amplifies attractiveness where it already exists but struggles to create it from scratch in declining areas.

These results lead to a clear conclusion: fiber optic does not act as a factor of territorial convergence. On the contrary, it tends to accentuate disparities between territories due to its dependence on local conditions such as human capital, economic density, accessibility, public services, etc.

Thus, fiber deployment does not automatically trigger development. It potentially amplifies latent economic dynamics in areas capable of exploiting them, but remains ineffective—or even negative—in the most vulnerable regions.

These findings reinforce the idea that digital infrastructure policies, if not integrated with local support mechanisms, risk exacerbating spatial inequalities. Fiber is a necessary but insufficient lever for territorial development. Its full effectiveness depends on an integrated approach, combining access to technology, economic stimulation, public services, and appropriate population policies.

In the final conclusion of the thesis, we will revisit these implications considering the initial objectives of the Plan France Très Haut Débit, the lessons from the literature, and potential recommendations for a fair digital policy.

8. General Conclusion.

he goal of this thesis was to empirically assess the economic effects of the progressive deployment of fiber optic broadband in rural French municipalities under the Plan France Très Haut Débit. By utilizing a difference-in-differences strategy with staggered cohorts (Callaway & Sant'Anna, 2021), we were able to leverage the temporal and spatial variability of the treatment to estimate the average effects of fiber installation on several key dimensions of local development: median income, unemployment rate, business creation, property prices, and population.

The results indicate that fiber optic installation is associated with a significant increase in median income starting from the first year following fiber deployment, with an upward trend continuing for up to three years. Similarly, the unemployment rate gradually decreases, suggesting improved integration or stability in the labor market. However, no positive effect was detected on business creation; the results even suggest a slight slowdown. Property prices, contrary to the expectation of a land premium, decrease in the most rural areas, and the population continues to decline, or even erodes further after fiber deployment.

Heterogeneity tests confirm that the effects of fiber are far from homogeneous. Only the densest rural municipalities (level 5) benefit clearly and consistently from the positive externalities of very high-speed broadband, while the most dispersed areas (level 7) show no tangible effects, and even exhibit signs of further divergence.

These results challenge the notion of a universal lever for rural development. Instead, fiber appears to be a conditional catalyst, producing significant effects only in territories that are sufficiently economically, socially, and spatially structured. In this sense, digital infrastructure is not an automatic remedy for territorial inequalities but can, without proper support, exacerbate existing disparities.

This work has several limitations. The panel covers a relatively recent period from 2016 to 2024, which limits the depth of post-treatment effects observed, particularly for the later cohorts. Furthermore, the absence of certain covariates (e.g., education level, age, type of economic activity) limits the possibility of fine-grained controls. The design relies on the assumed exogeneity of the fiber deployment timeline, which is a realistic assumption but would benefit from further investigation through complementary institutional analysis.

Despite these limitations, placebo tests and cross-validation by density strengthen the robustness of the results. The approach used could be enriched in future studies by applying machine learning methods or qualitative studies at the municipal level to better understand the underlying mechanisms.

These results call for a reevaluation of France's territorial digital strategy. While investment in infrastructure remains fundamental, it is not sufficient without a differentiated support policy tailored to the needs and capacities of each territory. This includes:

- Support programs for digital transition in rural businesses,
- Targeted actions for training, digital mediation, and residential attractiveness,

- Enhanced coordination between digital infrastructure and local development strategies.

In summary, fiber optic infrastructure is not an end in itself but a tool for revitalizing territories, which requires coherence, targeting, and support. This thesis shows that very high-speed broadband can transform local trajectories, but only where the necessary economic, social, and institutional conditions are in place to take full advantage of it.

9. Annexes.

All the R code used for data processing, panel construction, dynamic effect estimation via the Callaway & Sant'Anna (2021) method, as well as the figures presented in the thesis, is accessible through the following repository: :

https://github.com/DjamilaKamla/fiber-deployment-economic-impact

10. Bibliography.

10.1. Journal Articles.

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10.2. Datasets.

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