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Efectos socioeconómicos de la Digitalización. Impacto de la fibra óptica y del 5G en la movilidad de las personas en España.

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Resumen.

Este Trabajo de Fin de Grado analiza el impacto del despliegue de infraestructuras digitales de alta velocidad, específicamente la fibra óptica (FTTH) y la tecnología 5G, sobre la dinámica poblacional en los municipios españoles, en el contexto de la "España vaciada". Mediante un enfoque cuantitativo basado en datos de panel para el periodo 2013–2022, se emplea un modelo econométrico de efectos fijos que permite controlar la heterogeneidad no observable y analizar la relación entre conectividad y evolución demográfica. Los resultados muestran una relación positiva y estadísticamente significativa entre la expansión de estas tecnologías y el crecimiento o la retención de población. En particular, el aumento de la cobertura de FTTH y 5G se asocia con incrementos en la población municipal, incluso tras controlar por variables socioeconómicas como la renta y el desempleo. Esto sugiere que la mejora de la conectividad facilita el teletrabajo y reduce las desventajas de la localización geográfica, contribuyendo a mitigar la despoblación rural. No obstante, el estudio señala posibles problemas de endogeneidad, ya que la infraestructura puede desplegarse en áreas previamente más dinámicas. En conclusión, la digitalización se presenta como una herramienta clave para el reequilibrio territorial, cuya efectividad depende tanto de la disponibilidad como de la adopción de la tecnología.

Palabras clave: Fibra óptica, 5G, Despoblación, España vaciada, Movilidad, Teletrabajo.

Abstract.

This undergraduate dissertation examines the impact of high-speed digital infrastructure deployment, specifically fiber optics (FTTH) and 5G, on population dynamics across Spanish municipalities, within the context of the "Empty Spain" phenomenon. Using a quantitative approach based on panel data from 2013 to 2022, the study applies a fixed-effects econometric model to control for unobserved heterogeneity and assess the relationship between connectivity and demographic change. The results reveal a positive and statistically significant association between the expansion of these technologies and population growth or retention. Increased FTTH and 5G coverage is linked to higher municipal population levels, even after controlling for socioeconomic variables such as income and unemployment. These findings suggest that improved connectivity facilitates

remote work and reduces the disadvantages of geographic isolation, contributing to the mitigation of rural depopulation. However, the analysis also highlights potential endogeneity issues, as infrastructure deployment may be concentrated in already dynamic areas. Overall, the study concludes that digitalization is a key tool for territorial rebalancing, although its effectiveness depends not only on infrastructure availability but also on its adoption.

Keywords: Fiber optics, 5G, Depopulation, Empty Spain, Mobility, Teleworking.

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INTRODUCTION.

In the current era of rapid digital transformation, high-speed telecommunications infrastructure has shifted from a luxury to a critical utility, fundamentally reshaping the relationship between individuals and their geographical locations. The deployment of fiber optics (FTTH) and 5G technology represents a shift that challenges traditional economic models of urbanization and distance. This project examines this phenomenon within the specific context of Spain, a nation currently grappling with a severe territorial imbalance known as "Empty Spain" (*la España vaciada*), where vast rural areas face persistent economic stagnation and demographic decline (González-Val, 2025).

Gonzalez-Val (2025) also points out that rural depopulation in Spain is the result of a decades-long process that began during the rapid industrialization of the 1950s and 60s, leading to a massive internal out-migration of young adults to urban centers. Traditionally, the lack of infrastructure and basic services has driven these flows. However, he states that modern economic theory suggests that broadband expansion could serve as a vital tool to ensure the economic and demographic sustainability of these regions.

Also, the COVID-19 pandemic served as a massive, unplanned natural experiment for this digital mobility (Jamison and Wang, 2020). The forced shift toward Work from Home (WFH) demonstrated that for many sectors, physical presence in a central office is no longer a prerequisite for productivity. This project builds on the growing consensus that the availability of reliable, high-speed connections, particularly those supporting high upload speeds for video conferencing, is the primary bottleneck for the long-term viability of remote work in rural settings (McArthur and Hong, 2023).

METHODOLOGY.

This study adopts a quantitative empirical approach to evaluate the relationship between the deployment of high-speed telecommunications infrastructure and population dynamics across Spanish municipalities. The analysis relies on panel data, which allows

the observation of multiple municipalities over time and makes it possible to control for unobserved heterogeneity that may influence both infrastructure investment and demographic outcomes. The main explanatory variables capture the expansion of fiber optic broadband (FTTH) and 5G coverage, while the dependent variable reflects changes in population levels at the municipal level. Additional control variables are included to account for relevant socioeconomic factors that may affect population trends, such as income levels, labor market conditions, and demographic structure.

To address potential omitted variable bias and isolate the effect of digital infrastructure, the model is estimated using a Fixed Effects specification. This approach controls for time-invariant municipal characteristics, such as geographic location, historical development patterns, or structural economic conditions, which could otherwise bias the estimated relationship between connectivity and population change. Time fixed effects are also included to capture common shocks affecting all municipalities simultaneously, such as macroeconomic cycles or national policy changes. By exploiting within-municipality variation over time, this methodology improves the robustness of the estimated coefficients.

OBJECTIVES.

The main objective of this study is to analyze whether the expansion of digital infrastructure, specifically fiber optic broadband (FTTH) and 5G mobile networks, is associated with changes in population dynamics across Spanish municipalities. The analysis seeks to determine whether improvements in high-speed connectivity contribute to population growth or help mitigate population decline, particularly in rural areas that have historically faced structural disadvantages and demographic challenges. By examining variations in infrastructure deployment over time, the study aims to identify whether digital connectivity can be considered a relevant factor influencing residential location decisions in the context of increasing teleworking opportunities and digitalization of economic activity.

A secondary objective is to evaluate whether the effects of broadband expansion differ across municipalities depending on their socioeconomic characteristics. The analysis therefore considers the role of control variables such as income levels, unemployment rates, and demographic composition, allowing for a more comprehensive understanding of the mechanisms through which connectivity may influence population changes. Ultimately, the study aims to contribute empirical evidence to the debate on whether digital infrastructure policies can support more balanced territorial development and reduce disparities between urban and rural areas in Spain.

CHAPTER 1. LITERARY REVIEW.

We looked at what the literature says about the reasons that may drive an individual to move from one place to another. In other words, what are some of the factors said to increase mobility, findings state that 'closeness', as in how close one place is to another and how easy it is to move between them, "boosts mobility because there is a potential for better labour market matches in dense urban labour markets (Glaeser and Maré, 2001; Eriksson et al., 2008)" and that "urbanisation also increases the probability of individuals moving away from the region" (Simonen et al., 2016).

Thulin, & Vilhelmson (2014) highlighted that in general, people's willingness to relocate is shaped by how they weigh the potential benefits of better opportunities elsewhere against the desire for stability and attachment to their current place. For example, someone might decide to leave a place in search of better employment or higher salary, better education, or when family status changes; or even "to strengthen social ties, to change their housing or residential environment, or, more generally, to make a major life change (Boyle, 2009; Niedomysl, 2010a)" (Thulin and Vilhelmson, 2014).

The conditions and how developed a place is can also impact someone's decision to move in or out of an area, as demonstrated by some authors: "communities with a higher quantity and quality of infrastructure and amenities obtained increases in population, mostly from immigration, while communities with lower levels of infrastructure and amenities tended to lose population (e.g., Aschauer, 1989; Gramlich, 1994; Deller et al., 2001)" (Mahasuweerachai, 2010).

Furthermore, it is important to clarify that mobility does not refer solely to migration, but some investigators also include the use of means of transportation for different purposes, such as commuting to the workplace, as a way to measure people's mobility. This approach to the definition of "mobility" is used by Delclòs-Alió (2019) when studying how age can be related to Barcelona's citizens' mobility. He concluded that the reasons why young people are more "mobile" and spend longer times traveling

than older people is youngsters' close relationship with public transportation, which typically operates more slowly than private vehicles; and a higher proportion of work-related trips, which are more often made using motorized transport. This relationship becomes even clearer when territorial categories are incorporated into the analysis. However, this will not be the kind of mobility we will be focusing on in this paper. Nonetheless, it is true that access to public transportation and the connectivity a rural area has with a more urban area could also have an impact on rural immigration.

Moreover, when talking about people's mobility it is essential to mention the pandemic that paralyzed the world back in 2020. COVID-19 had a huge impact in people's mobility as it kept citizens from being able to go to their job physically, which promoted the expansion of the "Work from Home" initiative having people working online from their houses. Kim and Kwan exposed an investigation carried out by Lee et al. (2020) that looked closely at the early stages of COVID-19 in the U.S., and "concluded that various human mobility metrics (e.g., miles traveled per person) had decreased after the declaration of a National Emergency on March 13, 2020, which is in line with the conclusions from Huang et al. (2020b)" (2021, p.1).

For this reason, we can assume that those that did not have a purely physical job needed to stay at home connected to their coworkers, clients, etc. through Information and Communication Technologies (ICT) which are dependent on broadband and high-speed internet. This may have been a problem for those who needed or simply decided to leave to a less-developed area (proved by Mack et al. (2024) who hypothesized that the unfortunate onset of the COVID-19 pandemic may have accelerated the migration of people and businesses from urban areas to more rural regions) that might not have adopted measures to ensure quick internet access and connectivity. This is important to discuss because "faster connections were associated with increases in the frequency of home working" (McArthur and Hong, 2023) and it was brought to our attention by McArthur and Hong (2023) that during the pandemic, Ford et al. (2021) found that slow and inconsistent internet connectivity emerged as one of the most commonly reported issues experienced by individuals working from home. This is why their investigation concluded

that policymakers should recognize that the digital divide may constrain opportunities for remote work in the post-pandemic era. Regions with limited internet connectivity are inherently less conducive to home working (McArthur and Hong, 2023).

This leads us to believe that whether a person moves or decides to work in a rural area might be influenced by the accessibility of broadband and high-speed internet access technology that particular place has adopted. An analysis carried out by Lee and Leonard in 2023 showed that “nonmetro areas have had less access to high-speed internet even after controlling for relevant factors such as income and labor market conditions”.

These global trends find a critical case study in the Spanish context, where the debate on rural depopulation is framed within the concept of “*España vaciada*” (literally, the “Emptied Spain”). "*La España vaciada*" (Empty Spain) refers to the severe territorial and demographic imbalance in Spain, characterized by a continuous decline in population across vast rural and inland regions (González-Val, 2025). Cortés-Ruiz and Ibar-Alonso (2021) explained that this demographic crisis is particularly severe in provinces like Soria, Zamora, Teruel, and León, where residents have organized movements to highlight sociodemographic decline and the lack of essential services and infrastructure.

A critical but often overlooked aspect of this phenomenon is "forgotten urbanism”, where small rural municipalities suffer from outdated or non-existent planning tools. Nearly a quarter of Spanish territory, occupied by small rural towns, lacks a formal urban plan, leaving traditional village centers to decline (De-Santiago-Rodríguez, 2023). Modern infrastructure offers a potential path for resilience as some studies in Spain “indicate that a 10 % increase in broadband access leads to a 0.15 % and 0.08 % increase in local population and employment, respectively, in the short-term. Notably, this effect is more pronounced in small municipalities compared to larger cities” (González-Val, 2025).

This is something that has been broadly investigated since addressing the gap in rural broadband access is crucial, as the Internet has become an essential component of modern daily life (Mack et al., 2024, p.234). It was investigated even before the pandemic. For example, Prieger (2013), while investigating the economic benefits of broadband for rural areas, told us about an analysis carried out by Kolko in 2010 that concluded that:

> "Compared to areas that had no broadband providers, areas with one to three providers had 6.4% higher employment growth and 2.4% more population growth. Although the figures cited indicate that employment grew more than population, the research uncovered no significant effect of broadband on the employment rate. The author suggests that may be because people follow the jobs—not a bad outcome in itself for areas seeking to grow".

To try and understand why this inequality still happens, we took a look at what has been said about why certain rural areas have not adapted to broadband technologies and high-speed internet. This was Boases's (2010) object of investigation and he noticed that urban and suburban residents maintain an approximate 14–15% advantage over rural residents in Internet usage while broadband adoption is increasing across all area types, it remains proportionally higher among urban and suburban populations compared to their rural counterparts. He concluded that a big reason as to why some rural areas weren't adopting to the new technologies might have been their personal relations and surroundings. Rural populations are very different demographically from nonrural populations: "surveys have shown that people living in rural areas tend to be somewhat older, less educated, and more often work in lower status occupations than people in nonrural areas (e.g., Bell et al., 2004; Horrigan & Murray, 2006)" (Boase, 2010). As a result, if rural citizens don't have anyone in their surroundings that uses new technologies, they will not feel the need to use them either. Consequently, "simply making Internet infrastructure more available in rural areas may not completely erase these differences between rural and urban areas" (Boase, 2010, p.1266). Nevertheless, the development of Internet infrastructure in rural areas is necessary to achieve greater equality and attract people to the rural areas and improve living quality.

On the one hand, many researchers conclude that broadband and high internet access have a positive impact on the development of rural areas. This may result in the captivation of new citizens or even in the return of old citizens that decided to leave- One of this researchers is Prieger (2013) who wrote that "in the US, several studies have shown that output and employment are correlated with the deployment of broadband infrastructure". He also cited Stenberg et al. (2009) to tell us a few of the benefits of broadband which may be of particular interest for rural communities which include enhanced Internet access promotes community participation and creates additional opportunities for income generation via telework. It facilitates social interaction by lowering the barriers to civic and community engagement. Throughout the same paper, Prieger (2013) gives us a scoop of what he called "major findings": between 1998 and 2002, broadband availability contributed an estimated 1.0–1.4% to local employment growth and 0.5–1.2% to the growth rate of business establishments. Furthermore, broadband access was associated with a 0.3–0.6% increase in the proportion of businesses operating in ICT-intensive sectors. ICTs are very important to highlight because they can have a great impact in migration just as the research compiled by Cooke and Shuttleworth (2018) showed:

> "Several studies argue that ICTs enhance interregional migration by (a) improving the quality and quantity of spatial information on distant locales (Dekker & Engbersen, 2014; Dekker, Engbersen, & Faber, 2015; Thulin & Vilhelmson, 2014; Vilhelmson & Thulin, 2013), (b) permitting migrants to communicate more effectively with people and places left behind (Barcus & Brunn, 2010; Dekker & Engbersen, 2014; Komito, 2011), and (c) allowing more freedom to choose a place of residence less on the basis of proximity to a fixed place of work and more on the basis of other geographic characteristics such as natural and cultural amenities (Ettema, 2010; Mokhtarian, Collantes, & Gertz, 2004; Ory & Mokhtarian, 2006)".

In addition, many benefits have been mentioned when talking specifically about businesses and firms give that higher levels of broadband access in rural areas appear to

facilitate the establishment and attraction of businesses. Nonetheless, research indicates that rural firms, and possibly rural entrepreneurs, use ICTs and other broadband-related technologies less intensively than urban firms (Mack et al., 2024). Secondly, broadband reduces the transaction costs firms face when acquiring and applying knowledge. Unlike the first mechanism, where broadband is considered part of the knowledge itself, here it functions as an enabler of knowledge acquisition and utilization. For instance, in a broadband-enabled environment, industry-relevant knowledge can be rapidly disseminated to interested parties, and firms can more easily adopt new products and services that complement this knowledge (Prieger, 2013,). Lastly, Prieger (2013) also exposed that the relationship between technology and economic growth frames the connection between broadband and productivity in terms of whether the technology directly influences a firm's choices regarding inputs and production processes. From this perspective, the direct impact of an ICT, such as broadband, arises when a firm adopts the technology to reduce production costs and improve labor productivity by equipping workers with more effective tools.

On the other hand, there are some researches that have also pointed out the negative impact that broadband technologies, such as ICTs, may have on rural areas and their migration. For instance, adopting broadband in a rural area may increase mobility incoming into that area but may also reduce mobility outcoming from the rural area as people might decide to stay. This is exactly what Cooke and Shuttleworth (2018) brought to light when they stated:

> "Although ICTs may act to enhance migration by reducing some of the costs of migration, ICTs may likewise also reduce migration by diminishing the costs of staying. Specifically, before the advent of contemporary ICTs, the penalty associated with not migrating was quite high; immobility meant a reduced ability to access higher education (see Frenette, 2006), reduced career prospects (see Schaeffer, 1985), and isolation from friends and family who had already migrated (see Sjaastad, 1962). (…) Thus, the presumption that advanced ICTs contribute to a more hypermobile society is not necessarily valid with regard to all forms of geographic mobility. That is, although ICTs may be associated with

> intensified and altered daily mobility behavior, they may also, simultaneously, be associated with reduced residential mobility and interregional migration".

Moreover, "broadband is a double-edged sword for rural areas, and would address concerns that broadband opens previously insulated rural markets to outside competitors, which can produce negative outcomes for rural businesses (Anderson et al. 2003; Freathy and Calderwood 2016). Studies also suggest that the availability of broadband enables rural residents to seek jobs elsewhere, producing outmigration and the potential for brain drain from rural to urban areas. (Mahasuweerachai et al. 2010; Roberts and Townsend 2016; Townsend et al. 2017)" (Mack et al, 2024). Finally, another negative potential outcome of the adoption of broadband technologies on people's mobility is that "Just as some families maintain residences in two distinct locales and circulate between those residences on an irregular basis in order to minimise economic risk, ICTs may allow people to maintain their current residential location while simultaneously gaining access to a wider range of opportunities — both through actual shorter term geographical movement or through the internet — to minimise risk" (Cooke and Shuttleworth, 2018, p.9).

In conclusion, this paper seeks to examine whether the expansion of fiber optics and 5G to rural areas has an impact on their population and whether it is contributing to hindering rural depopulation in Spain as there hasn't been much research being done on this topic focusing on Spain. This could be an interesting topic to address. Something similar was already investigated some years ago (in 2009) in the U.S. as cited by Prieger (2013):

> "In one of the most careful studies of broadband's effect on the rural economy, Stenberg et al. (2009) used a quasiexperimental design approach to examine the impact of broadband on rural employment and income. Over the years 2002-2006, the "treatment group" of early adopting counties experienced more job growth, particularly in the nonfarm sector. Broadband available counties also

had more population growth in all years and higher personal income and nonfarm earnings growth in some of the years".

In addition, it would also be of high interest to research whether COVID-19 had an impact on people's mobility to rural areas in Spain by looking at and comparing data from both before and after the pandemic to see if being on lockdown influenced people to move from urban areas to rural areas, and whether having good internet access was a motivation to move to a rural area (even if the principal reason was either for logistic, economic or personal reasons) due to the (voluntary of forced) decision made by many companies of adapting to the telecommuting initiative. American researchers, such as Cooke and Shuttleworth (2018) have tried giving answers to this questions researching other authors but haven't really reached a clear conclusion, what they were able to understand from their literary review was that "ICTs may support working from home that would allow more freedom to choose a place of residence less on the basis of proximity to a fixed place of work and more on the basis of other geographic characteristics such as amenities (Ettema, 2010; Mokhtarian et al., 2004; Ory & Mokhtarian, 2006)". And, that the capacity to work remotely from home using ICTs does not necessarily lead to increased residential mobility. Instead, remote work often serves to mitigate the challenges of long commutes and, in some cases, may even encourage individuals to remain in their current location (Cooke and Shuttleworth, 2018). Others like Jamison and Wang (2020) directly reached a negative conclusion:

"We find that the presence of broadband had little measurable impact on people's tendencies to stay home during these weeks (…). Having broadband in their homes made people less likely to go to work. So, home broadband did not necessarily prompt people to stay home, but it did limit their going to their traditional workplaces.

Our main results for both staying home and visiting workplaces explain that the bulk of the reasons why people decide to stay home has to do with factors such as age, type of occupation, and level of education, not broadband. Broadband penetration itself seems to explain only a small portion of the changes in mobility trends in the U.S. in the second half of March and all of April".

But this could have been because, when they investigated, the pandemic was still too recent to have clear and complete results. For this reason, in my opinion, investigating this in Spain, a country rich in rural areas, some greatly developed and others that are falling behind in terms of broadband accessibility and high-speed internet availability, might be able to give us very interesting results and give us an approach to what could be done to help underdeveloped areas attract newcomers, as well as give a different point of view on a well-researched department as is the impact that COVID-19 has had in our lives by focusing on a variable such as the access to emerging technologies like broadband and 5G.

Also, the digital transformation in Spain, framed within the European Digital Decade 2030 (Márquez, 2024), has evolved from a technical necessity into a fundamental pillar for social and territorial cohesion. The massive deployment of Fiber-to-the-Home (FTTH) networks and the advancement toward next-generation systems, such as Radio-over-Fiber (Torres et al.), have established the infrastructure required for a new relationship between citizens and their territory. As noted by Roca (2024), this progress enables a more proactive and accessible Public Administration, effectively dismantling the geographical barriers that have historically driven rural flight. In this context, the present study analyzes whether this digital infrastructure is truly serving as a catalyst for demographic retention and regional rebalancing

This might have a huge impact given that some people that have investigated similar issues in other countries have concluded that the lack of equality when it comes to broadband technologies may compel workers to commute to the office, thereby preventing them from realizing the potential benefits of remote work. Additionally, substandard infrastructure may weaken economic resilience in the event of future restrictions or virus outbreaks that necessitate similar measures (McArthur and Hong, 2023) which is something that we should take into account because, just how we never saw COVID-19 and everything that it brought along coming, we should try and be as

prepared as possible in case something like what happened in 2020, and what it carried over for years on, ever happens again unpredictably.

CHAPTER 2. DESCRIPTIVE ANALYSIS.

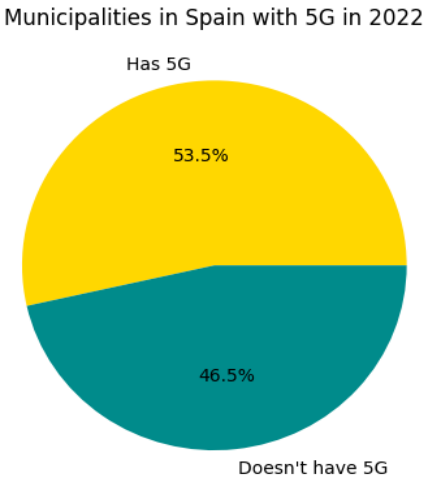
We are now going to perform a descriptive analysis with data from different sources in order to find answers to the questions raised in the chapter above. For this analysis we used the following variables:

- **CMUN**: Municipality code.
- **year**: Year.
- **4G**: Percentage of dwellings covered by 4G.
- **5G_dummy**: Binary variable (1 if 5G coverage > 0; 0 otherwise).
- **5G**: Percentage of dwellings covered by 5G.
- **Cob_100Mbps**: Percentage of dwellings covered by any technology with at least 100 Mbps speed.
- **VDSL_30Mbps**: Percentage of dwellings covered by ADSL/VDSL with at least 30 Mbps speed.
- **FTTH**: Percentage of dwellings covered by fiber optic network.
- **Edad_media**: Average age of the population.
- **Padron_Hombres_Espanola**: Number of Spanish-nationality men according to the population register.
- **Padron_Hombres_Extranjera**: Number of foreign-nationality men according to the population register.
- **Padron_Hombres_Total**: Total number of men according to the population register
- **Padron_Mujeres_Espanola**: Number of Spanish-nationality women according to he population register.
- **Padron_Mujeres_Extranjera**: Number of foreign-nationality women according to the population register.
- **Padron_Mujeres_Total**: Total number of women according to the population register.
- **Padron_Total_Espanola**: Total population of Spanish nationality according to the population register.
- **Padron_Total_Extranjera**: Total population of foreign nationality according to the population register.

- **Padron_Total**: Total population according to the population register.
- **Paro**: Number of unemployed people.
- **Porcentaje_hogares_unipersonales**: Percentage of single-person households.
- **Pob65**: Percentage of population aged 65 and over.
- **Pobmenor18**: Percentage of population under 18 years old.
- **Renta_neta_media_hogar**: Average net household income.
- **Renta_neta_media_persona**: Average net income per person.
- **Tamaño_medio_hogar**: Average household size.

To carry out this analysis, we first export our Excel file with all our data to Google Collab. Once it has been uploaded, and before we start looking at possible relations between variables, we take a look at what the situation was at the most recent year captured in our dataset (2022) in Spain. We specifically show the number of municipalities with 5G in 2022 in Spain using the "*5G_dummy"* variable. For this, we filter our dataset to only include records from the year 2022. Then, we use the *value_counts()* function on the "*5G_dummy*" variable to count how many municipalities have at least some 5G coverage (value 1) versus those with none (value 0). Finally, we generate a pie chart.

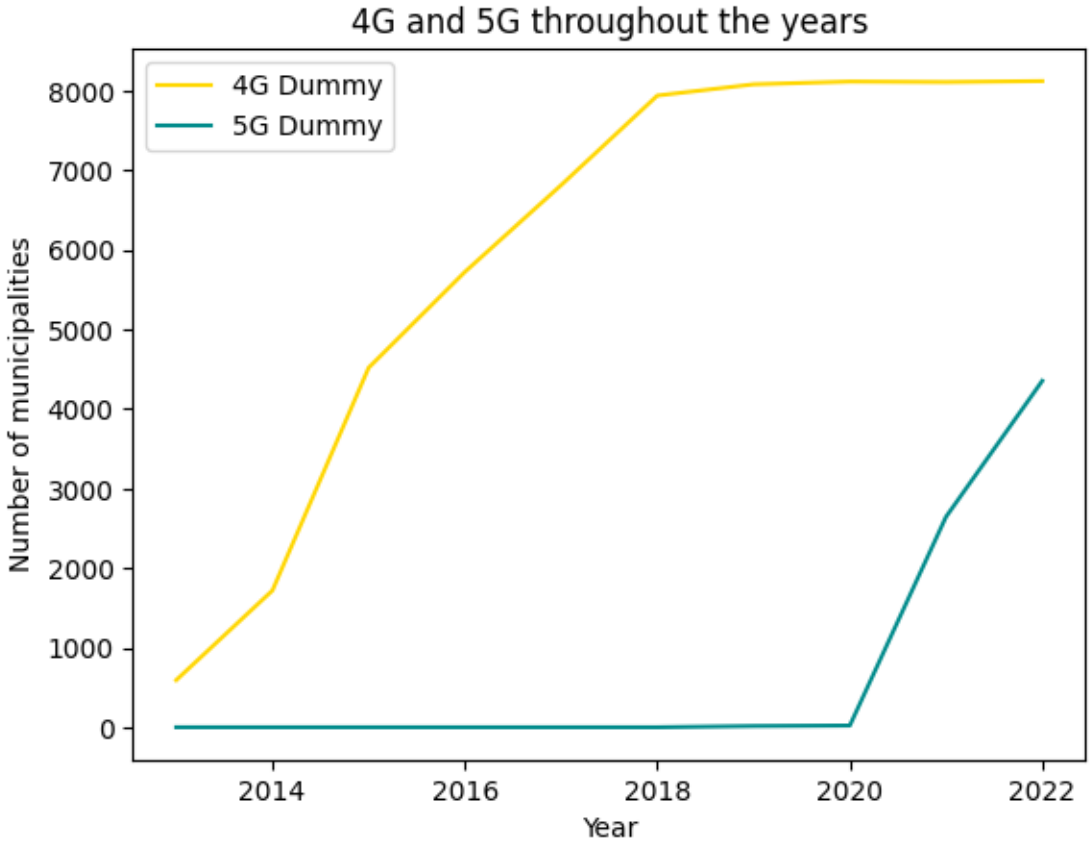
Figure 1. *Distribution of Municipalities with 5G Coverage in Spain (2022).*



Source: Own elaboration.

As we can see, even though the majority of municipalities in Spain had 5G in 2022, there were still a 46.5% of municipalities that didn't have access to it. This could be because 5G in 2022 was still rather new and what was more common at the time was 4G. For this reason, we decided to also generate a timeline to show the evolution of 5G and 4G in Spain throughout the years until 2022 using the variables "*4G_dummy*" and "*5G_dummy*". To track the technological evolution over time, we group the data by year and calculate the sum of the 4G_dummy and 5G_dummy variables. This effectively counts the total number of municipalities connected to each technology per year. We then plot these trends and obtain:

Figure 2. *Evolution of 4G and 5G Municipal Adoption in Spain (2013-2022).*



Source: own elaboration.

Figure 2 clearly shows that the turning point was around 2019. We see that 4G adoption shows rapid, steady growth starting from 2013, eventually plateauing around

2018-2019 as it reached near-universal municipal coverage and, meanwhile, 5G adoption remains at zero until a sharp, exponential spike begins in 2020. This perfectly contextualizes the introduction of 5G right around the onset of the COVID-19 pandemic. In other words, we see that from 2019 onwards, the number of municipalities that acquired 4G stalled while in 2020 the number of municipalities that implemented 5G internet rapidly increased going from 0 to almost 5,000.

Now that we have a general image on what the situation was in 2022 (the most recent data publicly available) and how the adaptation of higher-performing technologies has evolved through the years, we should look at how the different variables correlate with each other. To do this, we execute a correlation matrix for all our variables by creating a subset of our data frame containing only the relevant numerical variables. Python then calculates the Pearson correlation coefficient between every pair of variables. For the numbers to be visible, we had to divide the correlation table into three different tables.

Table 1. *Correlation Matrix 1.*

	CMUN	year	4G_dummy	4G	5G_dummy	5G	Cob_100Mbps	VDSL_30Mbps	FTTH	Edad_media
CMUN	1.000000	-0.000054	-0.037572	-0.036045	-0.026957	-0.023063	-0.052999	-0.047003	-0.064516	0.105783
year	-0.000054	1.000000	0.672528	0.741711	0.440422	0.341508	0.444717	-0.030919	0.515268	0.146290
4G_dummy	-0.037572	0.672528	1.000000	0.835993	0.184680	0.140934	0.344706	0.022986	0.348371	-0.052040
4G	-0.036045	0.741711	0.835993	1.000000	0.245209	0.188452	0.445123	0.017165	0.454097	-0.239028
5G_dummy	-0.026957	0.440422	0.184680	0.245209	1.000000	0.763148	0.387853	-0.036261	0.418390	-0.178059
5G	-0.023063	0.341508	0.140934	0.188452	0.763148	1.000000	0.321669	-0.035072	0.345370	-0.153499
Cob_100Mbps	-0.052999	0.444717	0.344706	0.445123	0.387853	0.321669	1.000000	0.005235	0.936178	-0.508343
VDSL_30Mbps	-0.047003	-0.030919	0.022986	0.017165	-0.036261	-0.035072	0.005235	1.000000	0.007746	-0.062040
FTTH	-0.064516	0.515268	0.348371	0.454097	0.418390	0.345370	0.936178	0.007746	1.000000	-0.492465
Edad_media	0.105783	0.146290	-0.052040	-0.239028	-0.178059	-0.153499	-0.508343	-0.062040	-0.492465	1.000000
Padron_Hombres_Espanola	-0.013938	0.000033	0.064592	0.084416	0.076543	0.062681	0.194435	-0.013827	0.180530	-0.122624
Padron_Hombres_Extranjera	-0.024020	0.004451	0.049903	0.065537	0.070472	0.056559	0.144583	-0.012681	0.140111	-0.094232
Padron_Hombres_Total	-0.015528	0.000676	0.063022	0.082410	0.076332	0.062341	0.188887	-0.013781	0.176233	-0.119189
Padron_Mujeres_Espanola	-0.012613	0.000084	0.060878	0.079776	0.073936	0.060102	0.184848	-0.013267	0.172079	-0.113596
Padron_Mujeres_Extranjera	-0.020153	0.005390	0.046769	0.061424	0.067891	0.053411	0.135708	-0.011788	0.132544	-0.086102
Padron_Mujeres_Total	-0.013746	0.000821	0.059337	0.077776	0.073604	0.059586	0.179296	-0.013153	0.167773	-0.110153
Padron_Total_Espanola	-0.013237	0.000060	0.062631	0.081966	0.075170	0.061321	0.189376	-0.013532	0.176072	-0.117853
Padron_Total_Extranjera	-0.022044	0.004941	0.048334	0.063478	0.069211	0.054989	0.140143	-0.012232	0.136343	-0.090103
Padron_Total	-0.014588	0.000753	0.061083	0.079972	0.074901	0.060893	0.183843	-0.013451	0.171786	-0.114428

Source: Own elaboration.

Table 2. *Correlation Matrix 2.*

	Padron_Total_Espanola	Padron_Total_Extranjera	Padron_Total	Paro
CMUN	-0.013237	-0.022044	-0.014588	-0.014285
year	0.000060	0.004941	0.000753	-0.018752
4G_dummy	0.062631	0.048334	0.061083	0.060350
4G	0.081966	0.063478	0.079972	0.078374
5G_dummy	0.075170	0.069211	0.074901	0.055878
5G	0.061321	0.054989	0.060893	0.062618
Cob_100Mbps	0.189376	0.140143	0.183843	0.183192
VDSL_30Mbps	-0.013532	-0.012232	-0.013451	-0.013764
FTTH	0.176072	0.136343	0.171786	0.159795
Edad_media	-0.117853	-0.090103	-0.114428	-0.133418
Padron_Hombres_Espanola	0.999858	0.935713	0.998427	0.966352
Padron_Hombres_Extranjera	0.930980	0.998870	0.947754	0.852341
Padron_Hombres_Total	0.998621	0.953132	0.999828	0.958251
Padron_Mujeres_Espanola	0.999889	0.938501	0.998850	0.961923
Padron_Mujeres_Extranjera	0.941307	0.999014	0.956716	0.856494
Padron_Mujeres_Total	0.998626	0.953352	0.999864	0.953895
Padron_Total_Espanola	1.000000	0.937309	0.998777	0.964125
Padron_Total_Extranjera	0.937309	1.000000	0.953394	0.855392
Padron_Total	0.998777	0.953394	1.000000	0.956094

Source: Own elaboration.

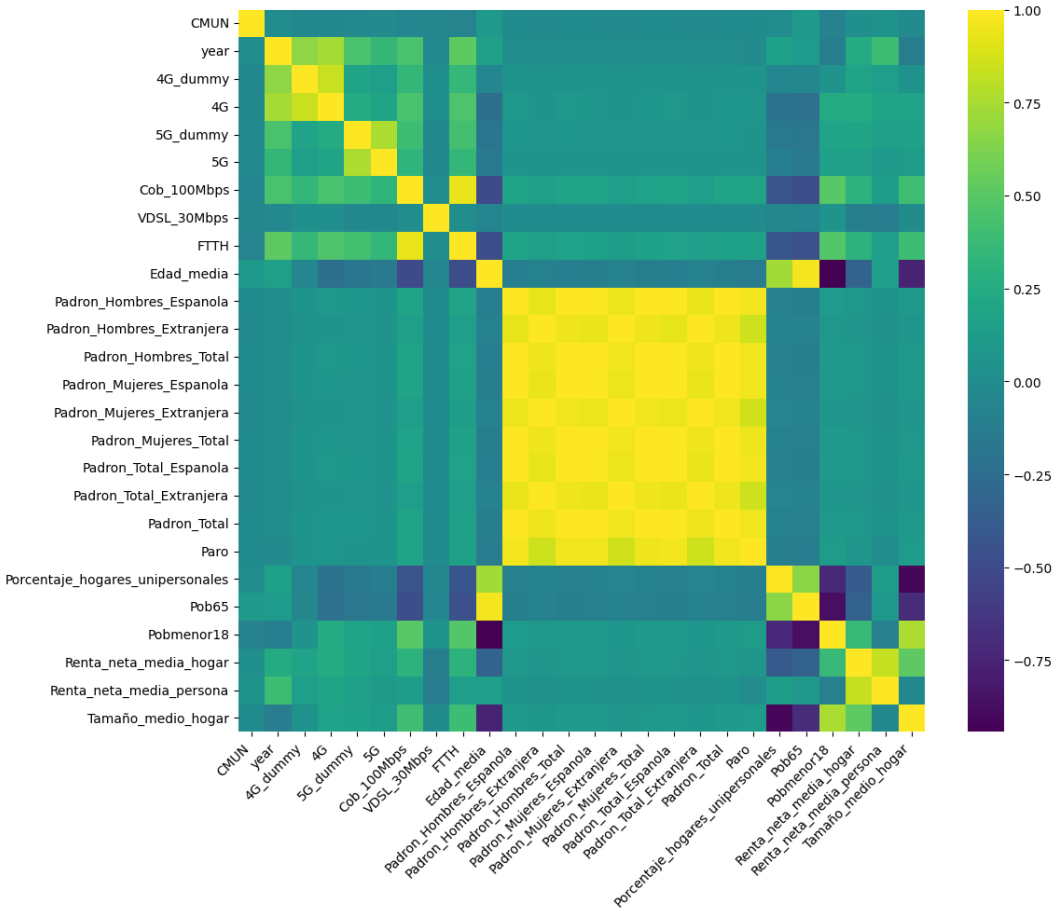
Table 3. *Correlation Matrix 3.*

	Porcentaje_hogares_unipersonales	Pob65	Pobmenor18	Renta_neta_media_hogar	Renta_neta_media_persona	Tamaño_medio_hogar
CMUN	0.010755	0.106349	-0.086628	0.027346	0.049784	-0.013080
year	0.156671	0.117089	-0.122213	0.246148	0.391785	-0.124857
4G_dummy	-0.050136	-0.046486	0.054554	0.180305	0.135156	0.032328
4G	-0.200629	-0.225457	0.243820	0.251992	0.192581	0.175337
5G_dummy	-0.154804	-0.173859	0.180443	0.187894	0.143669	0.153614
5G	-0.122947	-0.149845	0.152259	0.149163	0.110625	0.126357
Cob_100Mbps	-0.436846	-0.479037	0.498695	0.302684	0.129316	0.402567
VDSL_30Mbps	-0.042257	-0.047642	0.058707	-0.110897	-0.127139	-0.006313
FTTH	-0.419790	-0.465107	0.482177	0.302096	0.141690	0.388693
Edad_media	0.727386	0.964747	-0.943018	-0.337556	0.134793	-0.759910
Padron_Hombres_Espanola	-0.107129	-0.113056	0.112459	0.093307	0.038310	0.106409
Padron_Hombres_Extranjera	-0.072293	-0.085860	0.083249	0.072487	0.029995	0.079167
Padron_Hombres_Total	-0.102540	-0.109728	0.108807	0.091053	0.037419	0.103016
Padron_Mujeres_Espanola	-0.099215	-0.104574	0.103895	0.090103	0.040021	0.098146
Padron_Mujeres_Extranjera	-0.066321	-0.078587	0.075960	0.072205	0.033889	0.071915
Padron_Mujeres_Total	-0.094858	-0.101302	0.100322	0.088186	0.039429	0.094794
Padron_Total_Espanola	-0.102947	-0.108574	0.107933	0.091619	0.039222	0.102042
Padron_Total_Extranjera	-0.069264	-0.082168	0.079546	0.072414	0.032045	0.075480
Padron_Total	-0.098492	-0.105288	0.104335	0.089550	0.038487	0.098683

Source: Own elaboration.

Given the number of variables, we chose to also do a heat map correlation matrix for it to be more visual and be able to see higher correlation coefficients more easily.

Figure 3. *Heat Map of Pearson Correlation Coefficients between Connectivity and Socioeconomic Factors.*

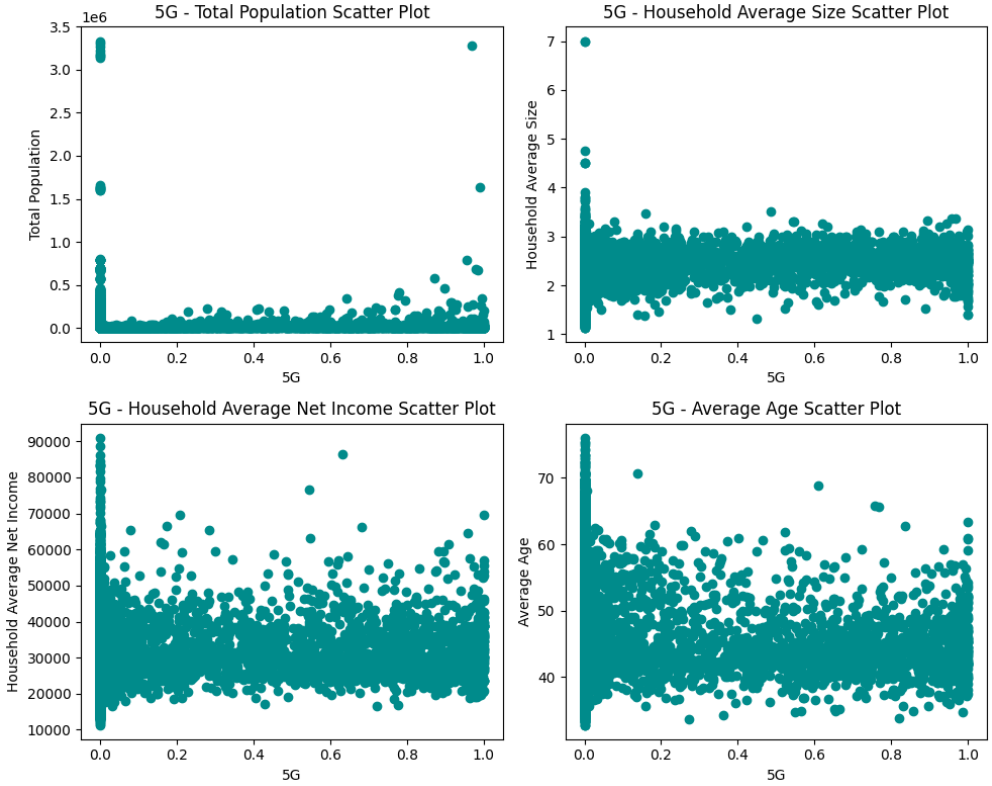


Source: own elaboration.

In the correlation matrix we can see that the availability of "*5G*" has a positive correlation with the variables "*Padron_Total*", "*Renta_neta_media_hogar*", and "*Tamaño_medio_hogar*": and a negative correlation with "*Edad_media*". That is, the percentage of dwellings covered by 5G seems to be positively related to the total population in the municipalities, the municipalities' homes' average net income, and the municipalities' average home size. However, the contrary happens to the percentage of

dwellings covered by 5G and the average age in each municipality. To further analyze this phenomenon, we looked at some scatter plots.

Figure 4. *Relationship between 5G Coverage and Key Demographic Indicators: Population, Household Size, Income, and Age.*



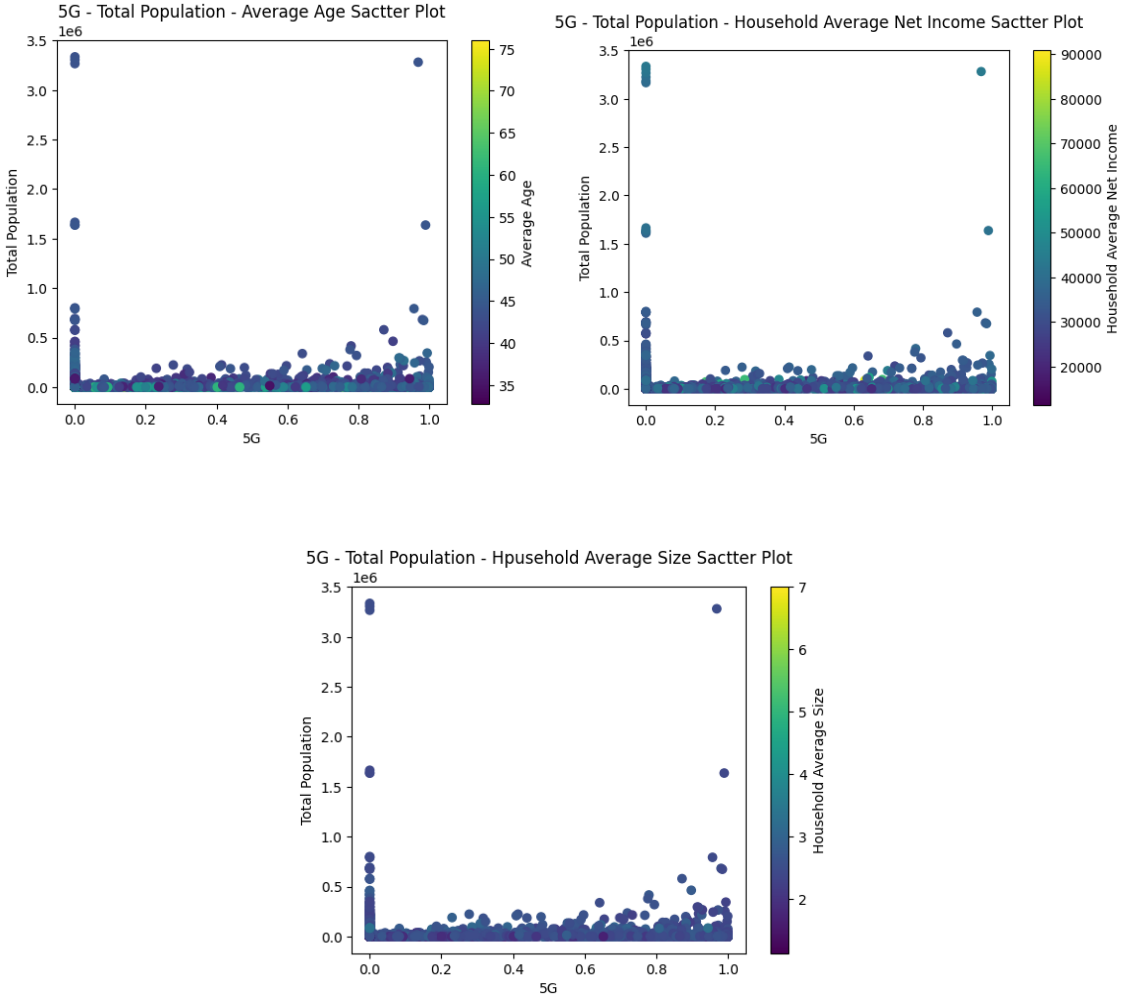
Source: own elaboration.

Figure 4 shows four scatter plots arranged in a 2×2 grid, each comparing a variable against a horizontal axis labeled “5G”. In the top-left plot titled “5G - Total Population Scatter Plot”, the vertical axis is labeled “Total Population”, and the points are widely dispersed, with a dense cluster of points appearing at lower population values and a few points extending much higher, indicating a broad range on the y-axis with some noticeable high-value outliers. The top-right plot, titled “5G - Household Average Size Scatter Plot”, has “Household Average Size” on the y-axis, and most points are concentrated in a relatively narrow vertical band, suggesting that values fall within a limited range, although there are a few points that extend higher than the main cluster. In the bottom-left plot, titled “5G - Household Average Net Income Scatter Plot”, the y-axis represents “Household Average Net Income”, and the points are spread across a moderate vertical range, with many observations forming a dense band in the middle and some scattered points both above and below that band. Finally, the bottom-right plot, titled “5G - Average Age Scatter Plot”, shows “Average Age” on the y-axis, where most points cluster within

a central range, with some dispersion upward and downward, indicating variability but still a noticeable concentration around mid-range values. Across all four plots, the horizontal axis labeled “5G” spans from low to high values, and the points appear distributed across this axis without forming any obvious linear pattern, resulting in clouds of points that vary in density and spread depending on the variable being plotted.

These scatter plots don’t show clearly the results from the correlation matrix. So, we try to combine some of these variables to see if we get any other information or conclusion.

Figure 5. *Multivariate Analysis of 5G Impact: Population Dynamics vs. Average Age, Income and Household Size.*



Source: own elaboration.

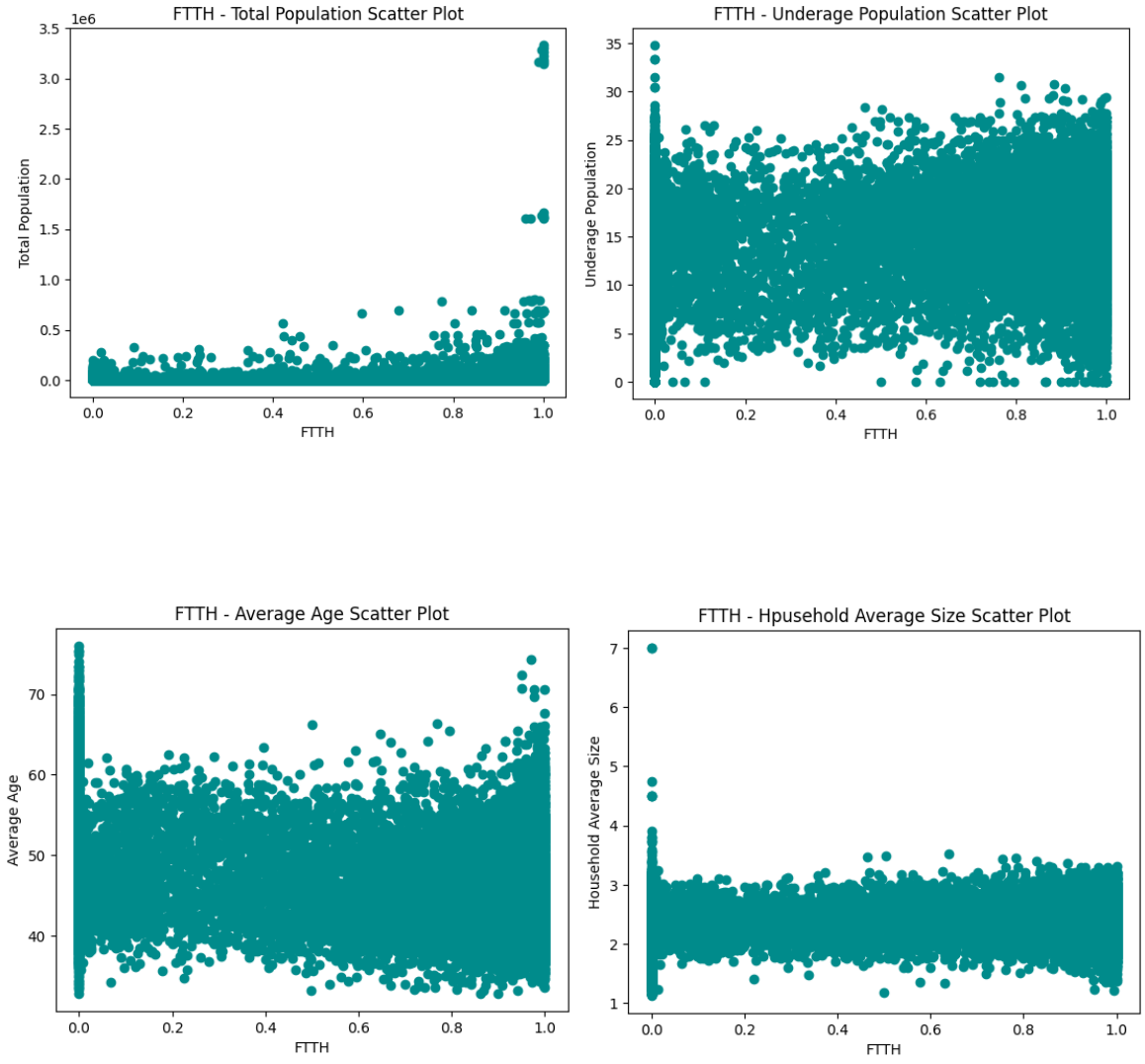
We now present three scatter plots that all share a similar structure, with “5G” on the horizontal axis and “Total Population” on the vertical axis, but each plot incorporates a different variable represented through a color scale shown in an adjacent color bar. In the top-left plot titled “5G - Total Population - Average Age Scatter Plot”, the points are distributed with a dense concentration at lower population values and a few points extending much higher, and the coloring of the points varies according to “Average Age”, as indicated by the color bar ranging from lower to higher values. The top-right plot, titled “5G - Total Population - Household Average Net Income Scatter Plot”, shows a similar spread of points across the same axes, again with most points clustered near the bottom of the population scale and some higher-value points standing out, while the color of each point reflects “Household Average Net Income”, with a color bar indicating the range of those values. In the bottom plot, titled “5G - Total Population - Household Average Size Scatter Plot”, the same general distribution pattern is visible, with a concentration of points at lower population levels and a smaller number of higher population observations, and the coloring corresponds to “Household Average Size”, as shown by the accompanying color bar. Across all three plots, the horizontal “5G” axis spans from low to high values, while the use of color adds an additional dimension to each plot, allowing differences in the third variable to be visualized alongside the position of each point.

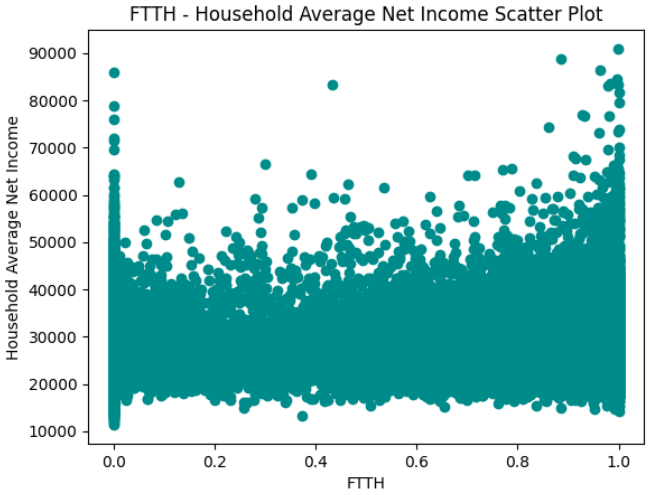
We can see that the municipalities that increase in population when 5G is increasingly implemented could be those with a lower average age, and those with low to medium average home net income and household size. The scatter plots show heavy clustering at 0.0 (no coverage) and 1.0 (full coverage). While the correlations exist, the visual spread is very wide, indicating a lot of variance.

This analysis leaves open the question of whether 5G has been deployed in areas with larger, wealthier, and younger populations, or whether its arrival has itself attracted population, especially young people, and generated economic gains reflected in higher incomes.

On the other hand, for the variable "*FTTH*" (the percentage of dwellings covered by fiber optic network) we see that it has a positive correlation with "*Padron_Total*", "*Renta_neta_media_hogar*", "*Tamaño_medio_hogar*", and "*Pobmenor18*" while having a negation correlation with "*Edad_media*". This is really similar to what we saw for the 5G variable. We will now look at these relations from a more specific point of view.

Figure 6. *Relationship between FTTH Coverage and Key Demographic Indicators: Population, Underage Population, Age, Household Size, and Income.*



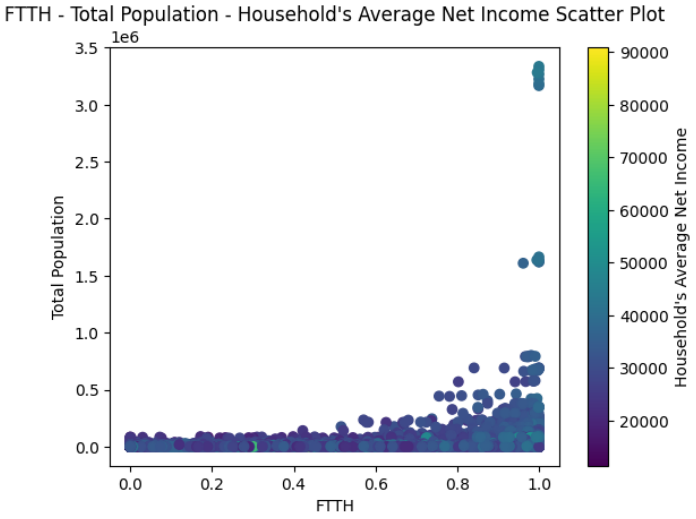


Source: own elaboration.

Figure 6 contains five scatter plots that are arranged in a grid, each using "*FTTH*" on the horizontal axis and comparing it with different demographic or household-related variables on the vertical axis. In the top-left plot titled "FTTH - Total Population Scatter Plot", the points are heavily concentrated at lower total population values, forming a dense cluster near the bottom of the graph, while a smaller number of points extend much higher, indicating a widespread with a few noticeably large values. The top-right plot, "FTTH - Underage Population Scatter Plot", shows a broad vertical distribution of points, with many observations forming a dense band across the middle of the y-axis and some dispersion above and below, suggesting variability in the underage population values. In the middle-left plot titled "FTTH - Average Age Scatter Plot", most points are concentrated within a central vertical range, with some spread upward and downward, creating a fairly continuous cloud of points without sharp clustering at extremes. The middle-right plot, "FTTH - Household Average Size Scatter Plot", displays a tighter vertical clustering compared to the others, with most points grouped within a relatively narrow band, though a few points extend higher than the main cluster. Finally, the bottom plot titled "FTTH - Household Average Net Income Scatter Plot" shows points distributed across a wider vertical range, with a dense concentration in the middle and some points extending toward higher values. Across all five plots, the FTTH axis runs from low to high values, resulting in varying densities and spreads depending on the variable being shown.

These graphs show a clear relation between the presence of optic network and the total population of the municipalities and the presence of optic network and the household's average net income. Let's see how these three variables relate within themselves.

Figure 7. *Multivariate Analysis of FTTH Impact: Population Dynamics vs. Income.*



Source: own elaboration.

Figure 7 is a scatter plot titled "FTTH - Total Population - Household's Average Net Income Scatter Plot", its horizontal axis is labeled "FTTH", and the vertical axis is labeled "Total Population". The points are spread across the full range of the FTTH axis, from low to high values, while the population values are heavily concentrated near the lower end of the y-axis, forming a dense cluster close to the bottom of the chart. A smaller number of points extend upward, creating a noticeable vertical spread that includes several higher population values and a few prominent outliers near the top of the plot. Each point is colored according to "Household's Average Net Income", as indicated by the color bar on the right, which transitions across a gradient representing lower to higher income values. The coloring varies across the plot without forming a distinct visual pattern tied to position, while the overall distribution of points remains uneven, with most observations tightly grouped at low population levels and fewer observations appearing at higher population values.

The plot confirms that municipalities with 100% FTTH coverage tend to capture the highest population and income peaks, but there are still many fully covered municipalities with low populations, suggesting technology alone doesn't guarantee a massive population.

These results make us, once again, question whether optic network has been deployed in areas with larger, wealthier, and younger populations, or whether its arrival has itself attracted population, especially young people, and generated economic gains reflected in higher incomes. The relationship appears slightly clearer visually, especially regarding population and income.

To continue our research, we decided to create a new variable called "*population growth rate*", that is, $(Padron_Total(t) - Padron_Total(t-1))/Padron_Total(t-1)$, and examine the correlations between "*5G"* and "*FTTH"* and this growth rate, in order to assess whether technology has accelerated migratory movements, or at least if the correlation suggests that this may be the case.

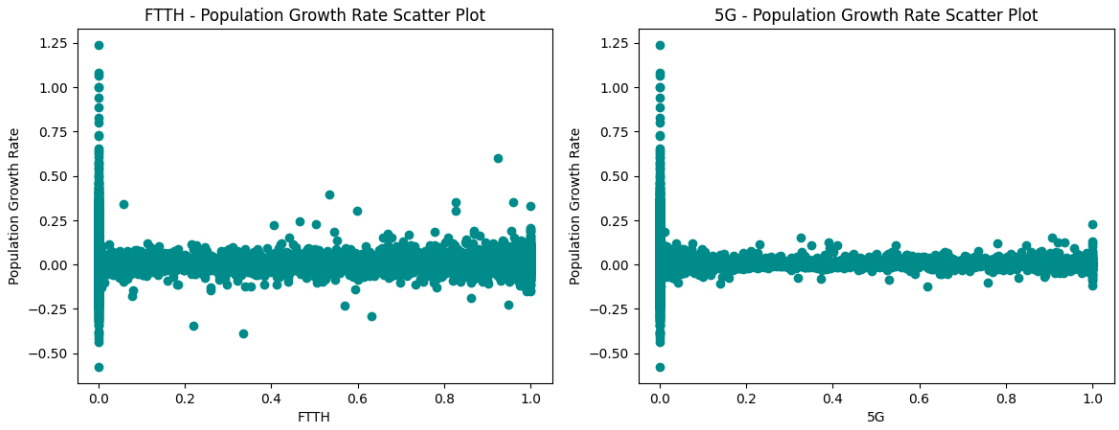
Table 4. *Correlation Matrix with Population Growth Rate.*

	5G	FTTH	population growth rate
5G	1.000000	0.345370	0.042229
FTTH	0.345370	1.000000	0.127694
population growth rate	0.042229	0.127694	1.000000

Source: own elaboration.

This correlation matrix shows a slight positive correlation between the "*population growth rate*" and both "*5G*" and "*FTTH*". Let's get a closer look at these correlations.

Figure 8. *Comparison of correlation between FFTH and 5G and the Population Growth Rate.*



Source: own elaboration.

Here we have two side-by-side scatter plots, each examining the relationship between population growth rate and a different variable. In the left plot titled "FTTH - Population Growth Rate Scatter Plot", the horizontal axis is labeled "FTTH" and the vertical axis is labeled "Population Growth Rate". The points are spread across the full FTTH range, but there is a noticeable vertical clustering of points near the lower end of the FTTH axis, where many observations are stacked and extend across a wide range of growth rate values, including both higher and lower extremes. Across the rest of the FTTH axis, the points form a relatively dense horizontal band centered around mid-range growth rate values, with fewer points appearing at the extremes. In the right plot titled "5G - Population Growth Rate Scatter Plot", the horizontal axis is labeled "5G", and the vertical axis remains "Population Growth Rate". A similar pattern is visible, with a strong concentration of points near the lower end of the 5G axis forming a vertical spread that covers a broad range of growth rate values. Beyond that region, the points are distributed across the axis in a relatively narrow horizontal band, indicating that most values cluster within a limited range of growth rates, with some scattered points extending above and below.

Looking at these scatterplots, the correlation seems clearer for FTTH than for 5G. They suggest that the greater percentage of FTTH coverage, the bigger the population

growth rate. Once again, we question whether this means that a larger presence of optic network in a municipality leads to population growth or if there is an increase of optic network because there is population growth.

The initial exploratory analysis, conducted through correlation heatmaps and bivariate visualizations, reveals a clear positive association between the rollout of advanced digital infrastructures, specifically FTTH and 5G, and several vital demographic markers, such as total population, household income, and a higher proportion of younger residents. While these patterns suggest that digital connectivity is deeply intertwined with municipal vitality, the scatter plots also highlight significant volatility and potential endogeneity. Specifically, these visual results leave open a fundamental question of causality: is the infrastructure acting as a magnet for growth, or is it simply being deployed in areas that already possess the demographic and economic characteristics required to support it?

To move beyond mere correlation and address this "chicken-or-egg" dilemma, a more sophisticated analytical framework is required. Simple cross-sectional observations cannot account for the unique, unobservable traits of each municipality that stay constant over time, such as geographic location or local culture. Therefore, the next chapter utilizes a Panel Data Linear Regression with Fixed Effects. By focusing on the variation within each municipality over the seven-year period, this model allows us to isolate the specific impact of technology deployment from other external factors, providing a much more rigorous assessment of whether digital investment truly serves as a catalyst for reversing rural depopulation.

CHAPTER 3: LINEAR REGRESSION.

In order to further verify the correlation between the variables in our dataset, we will carry out a linear regression model. To analyze the impact of high-speed broadband deployment on local population, this study employs an Econometric Panel Data Analysis. This approach is superior to simple cross-sectional models as it allows for the observation of specific dynamics within municipalities over time while controlling unobserved heterogeneity.

The empirical analysis is conducted using Python, leveraging the *pandas* and *NumPy* libraries for data processing, and the *linearmodels* library for the econometric estimation. The following sections detail the technical implementation of the model.

The dataset is structured as a Longitudinal Panel, tracking municipal-level data over several years. To address potential non-linearities and to stabilize the variance of the error terms, a natural logarithmic transformation is applied to the dependent variable (Population) and the income control variable:

$$\log_\text{pop} = \ln(Padron_Total)$$

$$\log\ _\text{icome} = \ln(Renta_neta_media_persona)$$

A critical step in the implementation is the definition of the panel index. The model uses a multi-index consisting of the municipal code (*CMUN*) as the cross-sectional identifier and the year (*year*) as the temporal identifier. This structure is essential for the software to correctly distinguish between within-entity and between-entity variations.

The study utilizes the PanelOLS (Panel Ordinary Least Squares) estimator. The choice of a Fixed Effects (FE) model is justified by the need to control unobserved heterogeneity. The specification is defined as follows:

1. **Entity Effects:** These capture all time-invariant characteristics specific to each municipality. This type of fixed effects captures unobservable and time-invariant aspects, such as cultural themes, customs, geographical characteristics, local idiosyncrasies, etc.
2. **Time Effects:** These account for shocks that affect all municipalities simultaneously in a given year. They act as a "buffer" that captures external events that could otherwise bias your results. A great example of this is the 2020 COVID-19 crisis.

To ensure the validity of the hypothesis testing, the model is estimated using Heteroskedasticity-robust standard errors (cov_type="robust"). This approach prevents the underestimation of standard errors and ensures that the p-values and confidence intervals remain reliable even if the variance of the residuals is not constant across the sample. These are the results we get by running the code:

Table 5. *FTTH Estimation summary.*

PanelOLS Estimation Summary

Dep. Variable:	log_pop	R-squared:	0.0482
Estimator:	PanelOLS	R-squared (Between):	-0.4876
No. Observations:	49567	R-squared (Within):	0.0749
Date:	Fri, Feb 06 2026	R-squared (Overall):	-0.4676
Time:	19:15:48	Log-likelihood	9.29e+04
Cov. Estimator:	Robust		
		F-statistic:	698.89
Entities:	8122	P-value	0.0000
Avg Obs:	6.1028	Distribution:	F(3,41436)
Min Obs:	1.0000		
Max Obs:	7.0000	F-statistic (robust):	339.04
		P-value	0.0000
Time periods:	7	Distribution:	F(3,41436)
Avg Obs:	7081.0		
Min Obs:	6549.0		
Max Obs:	8122.0		

Source: own elaboration.

Table 6. *FTTH Parameter Estimates.*

Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
FTTH	0.0230	0.0009	26.361	0.0000	0.0212	0.0247
log_income	-0.1652	0.0093	-17.766	0.0000	-0.1834	-0.1470
Paro	-3.282e-07	6.052e-08	-5.4235	0.0000	-4.469e-07	-2.096e-07

F-test for Poolability: 7033.3
P-value: 0.0000
Distribution: F(8127,41436)

Included effects: Entity, Time

Source: own elaboration.

In this case, the estimation results for the Fixed Effects (PanelOLS) model provide robust evidence regarding the impact of digital infrastructure on municipal demography:

Firstly, the variable of interest, *FTTH*, shows a positive coefficient of 0.0230, which is statistically significant at the 1% level ($p < 0.01$). This result suggests that the deployment of Fiber technology is a significant driver of population retention or growth. Specifically, an interpretation for these results is that a one percentage point increase in fiber coverage is associated with a 2.3% increase in the population, *ceteris paribus* (the rest remaining constant). This proves that digital connectivity plays a vital role in maintaining and growing local populations. Also, we can see that we got extremely similar results to what Kolko in 2010 (cited by Prieger, 2013) got for the United States when he found that regions serviced by one to three broadband providers experienced an employment growth rate 6.4% greater, alongside a population increase 2.4% higher, than regions completely lacking broadband infrastructure.

In addition, regarding the economic controls, *log_income* yields a negative and significant coefficient (-0.165), suggesting that population dynamics in the sample may be influenced by factors beyond purely monetary wealth, such as the cost of living or

industrial shifts. Furthermore, unemployment (*Paro*) shows the expected negative sign, confirming that municipalities with higher jobless rates experience greater population decline, although the magnitude of this effect is relatively small.

Finally, the model demonstrates high internal validity. The F-test for Poolability ($p < 0.01$) strongly rejects the null hypothesis that a simple OLS regression would be sufficient, thereby validating the use of Entity and Time Fixed Effects. While the Within R-squared stands at 7.49%, it is important to note that in social science panel data with fixed effects, this value is standard, as the model focuses on explaining the variation over time rather than the absolute population levels.

To conclude, the econometric analysis confirms that digital infrastructure is a vital tool in the fight against depopulation. Specifically, the statistically significant positive coefficient of the FTTH variable demonstrates that expanding fiber optic access leads to a measurable increase in municipal residents. By taking into account income and unemployment through a Fixed Effects framework, the model proves that this demographic growth is not merely a result of economic trends but is actually directly linked to the availability of high-speed connectivity. Ultimately, these findings suggest that digital investment is a key driver for territorial cohesion, providing a viable pathway for revitalizing rural areas and balancing regional development.

Now, we do another linear regression but using the variable "*5G*" as the variable of interest. Once we have substituted the variable FTTH for the 5G variable, we run the code and here are the results we obtain:

Table 7. *5G Estimation Summary.*

PanelOLS Estimation Summary

Dep. Variable:	log_pop	R-squared:	0.0413
Estimator:	PanelOLS	R-squared (Between):	-0.4790
No. Observations:	49581	R-squared (Within):	0.0589
Date:	Fri, Feb 20 2026	R-squared (Overall):	-0.4595
Time:	11:01:44	Log-likelihood	9.274e+04
Cov. Estimator:	Robust		
		F-statistic:	594.74
Entities:	8124	P-value	0.0000
Avg Obs:	6.1030	Distribution:	F(3,41448)
Min Obs:	1.0000		
Max Obs:	7.0000	F-statistic (robust):	233.03
		P-value	0.0000
Time periods:	7	Distribution:	F(3,41448)
Avg Obs:	7083.0		
Min Obs:	6549.0		
Max Obs:	8122.0		

Source: own elaboration.

Table 8. *5G Parameter Estimates.*

Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
cobertura_5G	0.0382	0.0021	17.983	0.0000	0.0341	0.0424
log_income	-0.1620	0.0092	-17.631	0.0000	-0.1800	-0.1440
Paro	-3.342e-07	6.209e-08	-5.3822	0.0000	-4.559e-07	-2.125e-07

F-test for Poolability: 9260.9
P-value: 0.0000
Distribution: F(8129,41448)

Source: own elaboration.

Looking at these results, the first thing we notice is that the regression analysis reveals a positive and highly statistically significant relationship between the deployment of next-generation telecommunications infrastructure and municipal population dynamics. Specifically, the estimated coefficient for the 5G coverage variable is 0.0382, accompanied by a p-value of 0.0000, indicating robust significance at the 1% level.

Since the dependent variable representing population is specified in logarithmic terms (*log_pop*), while the independent variable of interest is measured as a proportion from 0 to 1 (where 1 represents 100% coverage), the coefficient is interpreted as a percentage change. Consequently, holding all other control variables and unobserved fixed effects constant, transitioning from zero to full 5G coverage within a municipality is associated with a 3.82% increase in its population. Specifically, achieving full 5G coverage is linked to a roughly 3.8% demographic expansion in the affected areas, underscoring the vital role of modern digital connectivity in shaping regional demographic trends. Ultimately, these results suggest that the deployment of 5G infrastructure has a substantial and highly significant impact on population retention or growth. This is just as Cooke and Shuttleworth (2018) stated when they argued that ICTs diminish the costs of staying in one place, reducing outmigration because people are no longer isolated and can access remote work. They also noted that remote work mitigates long commutes and encourages people to stay in their current location. Our positive FTTH and 5G coefficients capture this exact "retention" effect.

On the other hand, regarding the socioeconomic control variables included in the model, the results reveal significant demographic dynamics related to local income and employment levels. The coefficient for average net income (log_income) is estimated at -0.1620 and is statistically significant at the 1% level (p-value = 0.0000). Because both the dependent variable and the income variable are logarithmically transformed, this coefficient acts as an elasticity, indicating that a 1% increase in a municipality's average net income is associated with a 0.16% decrease in its population. Rather than suggesting that individuals leave high-income areas in search of better job opportunities, this negative relationship may instead reflect cost-of-living pressures. Municipalities with higher average incomes often also exhibit higher housing prices and general living costs, which can incentivize certain population groups, particularly younger individuals or lower-income households, to relocate to more affordable areas. In this sense, the coefficient may be capturing the effect of affordability constraints, such as the housing problems is larger cities like Madrid or Barcelona, where high income levels coexist with significant barriers to residential access.

Similarly, the model captures a highly significant, negative relationship between unemployment (*Paro*) and population growth. The estimated coefficient of negative 0.0000003342 (*p-value = 0.0000*) confirms that higher unemployment levels are linked to demographic decline, aligning with the theoretical expectation that individuals will emigrate from areas with constrained labor markets in search of better job opportunities. Although the mathematical magnitude of this coefficient appears remarkably small, this is primarily an artifact of the variable's scaling; Paro is measured in raw aggregate totals rather than as a proportional unemployment rate, thereby shrinking the numerical size of the coefficient without diminishing its statistical or economic relevance.

Finally, regarding the explanatory power of the model, the Within R-squared value stands at 0.0589, indicating that the independent variables account for approximately 5.9% of the variation in population within individual municipalities over time. Although this figure may initially appear low, it is a standard and widely accepted outcome in Fixed Effects panel data models, as the entity fixed effects inherently absorb a substantial portion of the static, cross-sectional variation. Furthermore, the robustness of this specification is confirmed by the F-test for poolability, which yielded a statistic of 9260.9 ($p < 0.01$). This highly significant result strongly rejects the null hypothesis that unobserved individual effects are non-existent, thereby validating that the inclusion of Entity and Time Fixed Effects was strictly the appropriate econometric approach for this analysis.

CHAPTER 4. CONCLUSIONS.

The empirical findings of this study suggest that digital infrastructure plays a statistically significant role in shaping population dynamics across Spanish municipalities. Both fiber optic broadband and 5G coverage show positive associations with population growth, even after controlling for income levels, unemployment, and unobserved municipal characteristics. These results indicate that investment in high-speed connectivity can contribute to mitigating rural depopulation by enabling remote work and reducing the economic disadvantages of geographic isolation. Consequently, digital infrastructure policy should be viewed not merely as a technical project, but as a strategic territorial cohesion tool for balanced regional development.

An additional mechanism through which digital connectivity may contribute to territorial rebalancing relates to spatial differences in housing costs and general living expenses. If high-speed internet allows workers and firms to operate effectively from geographically distant locations, regions with lower housing prices and lower cost of living may become increasingly attractive relative to large cities. In this context, digital infrastructure can make it easier to access good jobs without facing high housing costs. Remote work and digital business activity may allow smaller or more remote municipalities to benefit from their advantages, such as lower housing costs, better quality of life, and less congestion. This dynamic could help explain why improved connectivity may contribute not only to population retention but also to the attraction of new residents and economic activity in previously disadvantaged areas.

To be effective, broadband policy must be tailored to specific objectives. Reducing the digital divide can help small municipalities adapt to demographic challenges, but effective design requires a multi-level approach balancing regional coordination with targeted local interventions (González-Val, 2025). Critically, however, the demographic effects of broadband expansion often materialize only after several years (Lehtonen, 2020). This lag explains why current economic benefits may appear limited. To move beyond this "second-best" outcome, the focus must shift from purely technical expansion to addressing adoption barriers. Successful transformation requires identifying factors

that prevent residents from utilizing new infrastructure, rather than assuming coverage alone generates economic momentum (Moral-Arce et al., 2025).

While the econometric results provide evidence of a positive relationship between deployment and growth, the analysis also highlights the complexity of identifying a purely causal mechanism. Digital infrastructure may act as both a driver and a consequence of economic development; growing municipalities attract investment, which in turn reinforces their attractiveness.

Future research could extend this analysis by incorporating indicators such as firm creation rates, productivity, or teleworking intensity. Moreover, exploring regional heterogeneity could reveal whether impacts differ between metropolitan and sparsely populated regions. Ultimately, understanding these socioeconomic effects remains essential for designing effective regional development policies.

In addition, several limitations should be acknowledged when interpreting the results of this study. One important constraint is the lack of more recent data at the municipal level, which limits our ability to capture the most up-to-date population dynamics, particularly those that may have emerged after the consolidation of remote work practices following the COVID-19 pandemic. This temporal limitation may prevent the analysis from fully reflecting recent migration patterns toward rural areas.

Furthermore, the study does not explicitly address the potential issue of endogeneity. While the analysis assumes that the deployment of broadband and 5G infrastructure may influence population changes in rural areas, it is also possible that the causal relationship operates in the opposite direction, meaning that areas experiencing population growth or greater economic dynamism may be more likely to receive earlier technological investment. Therefore, future research could benefit from the use of causal inference strategies, such as instrumental variables or quasi-experimental designs, to

better isolate the direction of the relationship between digital infrastructure and demographic change.

To conclude, the success of rural broadband initiatives must be measured by more than just kilometers of fiber optic cable or percentages of 5G coverage. While building this infrastructure is a necessary first step to ensure regional balance, it is only the beginning of a much larger process. For these investments to translate into tangible economic impacts, such as creating jobs, boosting digital trade, and improving public services, policymakers must close the gap between availability and adoption. By shifting the focus toward overcoming socio-economic barriers and fostering digital literacy, Spain can ensure that high-speed connectivity acts not just as powerful driver for rural growth rather than just a technical utility.

DECLARACIÓN DE USO DE HERRAMIENTAS DE INTELIGENCIA ARTIFICIAL GENERATIVA EN TRABAJOS FIN DE GRADO.

Por la presente, yo, Blanca María García-Mayoral Peña, estudiante de E-3 Analytics de la Universidad Pontificia Comillas al presentar mi Trabajo Fin de Grado titulado "Impacto de la fibra óptica y del 5G en la movilidad de las personas en España", declaro que he utilizado la herramienta de Inteligencia Artificial Generativa ChatGPT u otras similares de IAG de código sólo en el contexto de las actividades descritas a continuación:

1. **Brainstorming de ideas de investigación:** Utilizado para idear y esbozar posibles áreas de investigación.
2. **Referencias:** Usado conjuntamente con otras herramientas, como Science, para identificar referencias preliminares que luego he contrastado y validado.
3. **Metodólogo:** Para descubrir métodos aplicables a problemas específicos de investigación.
4. **Interpretador de código:** Para realizar análisis de datos preliminares.
5. **Corrector de estilo literario y de lenguaje:** Para mejorar la calidad lingüística y estilística del texto.
6. **Sintetizador y divulgador de libros complicados:** Para resumir y comprender literatura compleja.
7. **Revisor:** Para recibir sugerencias sobre cómo mejorar y perfeccionar el trabajo con diferentes niveles de exigencia.
8. **Traductor:** Para traducir textos de un lenguaje a otro.

Afirmo que toda la información y contenido presentados en este trabajo son producto de mi investigación y esfuerzo individual, excepto donde se ha indicado lo contrario y se han dado los créditos correspondientes (he incluido las referencias adecuadas en el TFG y he explicitado para que se ha usado ChatGPT u otras herramientas similares). Soy consciente de las implicaciones académicas y éticas de presentar un trabajo no original y acepto las consecuencias de cualquier violación a esta declaración.

Fecha: 16 de abril de 2026.

Firma: _____BGMP_____

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