DIGITISATION: ECONOMIC AND SOCIAL IMPACTS IN RURAL AREAS

PAN-EUROPEAN ASSESSMENT REPORT

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Table of contents

1. Introduction

The Pan-European Assessment Report within the Horizon 2020 project DESIRA aims to give an overview of the current state of digitalisation in rural areas across Europe and the corresponding impact on the socioeconomic performance of these regions. The task is based on

- the construction of a Rural Digitisation Index based on the disaggregation of the existing DESI (Digital Economy and Society Index) and complemented by primary data collection;
- mapping the degree of digitalisation in European rural areas using Eurostat's NUTS 2016 classification and urban-rural typology;
- the development of robust causal mechanisms linking different degrees of digitalisation to the socioeconomic performance of rural areas.

The importance of digitalization is rapidly increasing in Europe, but evidence at a Pan-European level is often lacking. Moreover, current empirical research assessing the role of digitalization in Europe is almost exclusively focused on state-wide analysis rather than mapping crucial regional differences. One reason is the absence of a widely accepted theoretical cornerstone offering support to empirical studies, as the main determinants of successful digital implementation and its wider economic and societal consequences remain unknown regardless the geographical scope.

This report attempts to fill in some of the empirical gaps in the existing literature by departing from the European Commission's Digital Economy and Society Index (DESI) – an important and widely accepted indicator for the current state of digitalization across the European Union's Member States – and identifying key elements for digitalization at more disaggregated regional levels. Chapter 2 deals with this issue and additionally presents an overview of the available regional data. Chapter 3 maps these identified key variables to give an overview of the current state of rural digitalization across Europe in terms of fixed broadband coverage. An overview of existing literature and a subsequent quantitative analysis in chapter 4 assesses the impact of broadband infrastructure on regional economic growth.

2. Rural Digitisation Index

The first main objective of this report is to construct a Rural Digitisation Index that reflects the digital performance of European rural areas in certain key areas. Three tasks can be identified in order to achieve this objective – two primary tasks and one second-stage task:

Table 1: Objectives for the construction of the Rural Digitisation Index.

First-stage objectives	**(1)** Adopt a regional classification that allows for a distinction between urban and rural areas across Europe.	**(2)** Identify key dimensions that constitute the digital competitiveness of socioeconomic entities.
Second-stage objective	**(3)** Collect secondary and primary data to quantify the key digital dimensions within the specified regional classification.	

The following subchapters discuss these tasks. First, we define Eurostat's urban-rural typology to stake out the different regions that will set the scene for the forthcoming analysis. Then, we introduce the Digital Economy and Society Index (DESI) provided by the European Commission as our basis for the identification of key regional digitalisation variables. These constitute the first-stage objectives. Finally, the regional classification and digitalisation dimensions are merged, and we discuss our data collection strategy.

2.1. Regional classification

We adopt Eurostat's urban-rural typology based on data for 1 km² population grid cells[1]. Rural grid cells and urban clusters are labelled according to their population densities and absolute number of inhabitants, and are further adjusted based on surface area and the presence of main cities in order to establish the following classification:

[1] Source: https://ec.europa.eu/eurostat/statistics-explained/index.php/Territorial_typologies_manual_-_urban-rural_typology.

- **Predominantly urban regions**: NUTS level 3 regions where at least 80% of the population live in urban clusters.
- **Intermediate regions**: NUTS level 3 regions where more than 50% but less than 80% of the population live in urban clusters.
- **Predominantly rural regions**: NUTS level 3 regions where at least 50% of the population live in rural grid cells.

NUTS 3 is the deepest level of the Nomenclature of territorial units for statistics (abbreviated NUTS) maintained by Eurostat to divide the European Union's economic territory using a common classification of territorial units. The classification is frequently updated[2] (the latest two versions date from respectively 2016 and 2021), which often poses challenges for the consistency of current and past longitudinal data collected within this classification due to boundary shifts, mergers, and divisions that tend to accompany the updates.

Figure 1 contains a graphical NUTS level 3 representation of the European Union's geographical area. The colour codes designate the three categories resulting from the applied urban-rural typology. 430 predominantly rural regions are identified out of 1348 NUTS level 3 regions in total. Furthermore, 363 predominantly urban regions and 555 intermediate regions can be distinguished. Due to the timing of this report and the availability of secondary data at the time of writing, we have adopted the 2016 version of the NUTS classification rather than the 2021 update.

[2] Source: https://ec.europa.eu/eurostat/web/nuts/history.

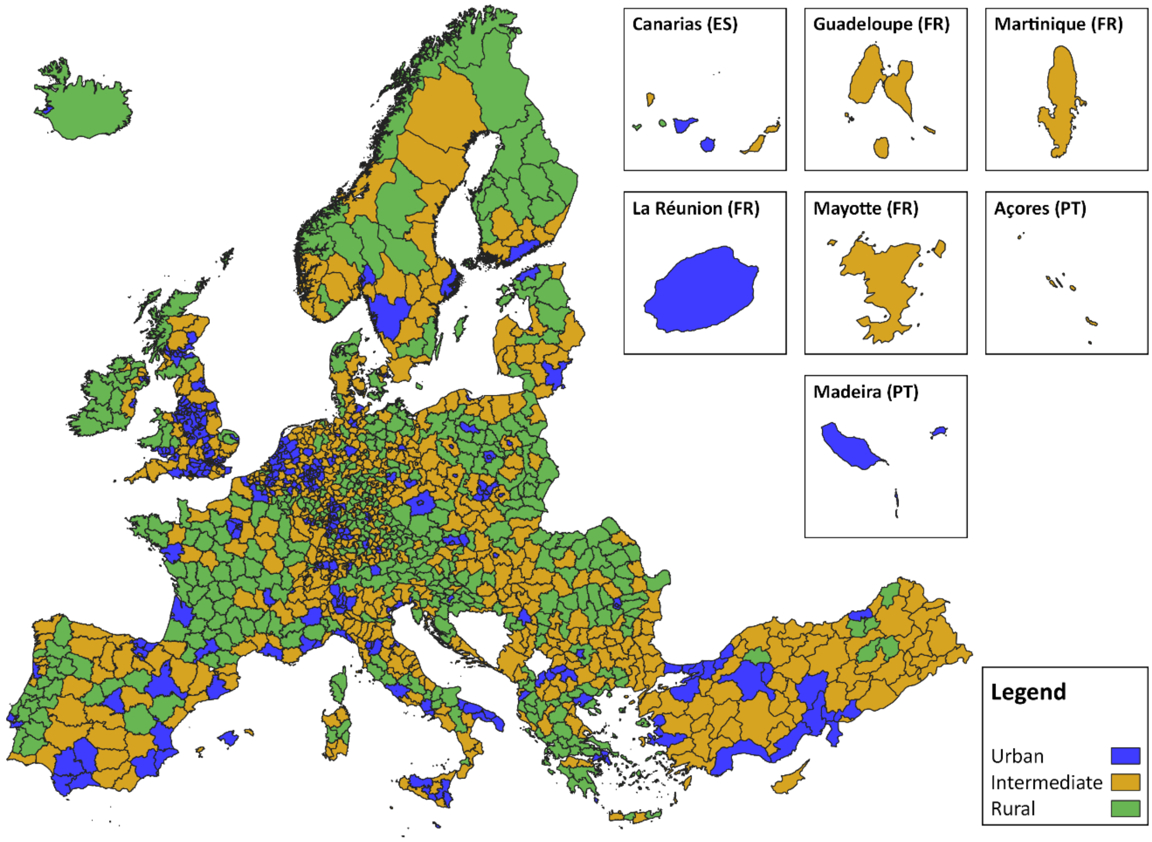

Figure 1: NUTS level 3 representation of Eurostat's urban-rural typology of the European Union and the United Kingdom.

2.2. Digital dimensions

Since 2015, the European Commission monitors the digital evolution of its Member States through their Digital Economy and Society Index (DESI)[3]. The index is designed at the national level (NUTS 0) and assists Member States in designing priority reforms specifically targeted at certain key dimensions in the digital economy for which progress is relatively slow. The DESI reports are published annually based on data from the preceding year.

Five principal policy areas (comprising 37 different indicators) have been identified which are meant to represent the wide spectrum of individual and collective possibilities introduced through digitalisation. Although the DESI allows the identification of troublesome gaps in the spectrum, the main proposition behind the scheme is that progress and favourable development can only be attained through concerted and simultaneous improvements across all dimensions. The different dimensions nevertheless serve distinct (but interconnected) purposes. Table 2 gives an overview of the main dimensions while table 3 presents the sub-dimensions and corresponding indicators. The

[3] Source: https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi.

connectivity dimension reflects the population's ability to access the Internet and forms an eligibility condition for a region to take advantage of the wider spectrum. Moreover, connectivity in terms of broadband infrastructure and download/upload rates can be regarded as a crucial element defining contemporary competitiveness (Stoica & Bogoslov, 2017). While the capability to access the Internet qualifies consumers and enterprises to benefit from digitalisation, its success is to a certain extent determined by the level of human capital with regards to internet user skills and more technical expertise. Digital human capital is important for the development and implementation of digital technologies and digital public services, but users and consumers also need a certain baseline skill level in order to use these technologies and services and work their way around them. There is an increasing prevalence of online fraud and scams specifically targeted at vulnerable online groups which can be counteracted through increased digital human capital.

A potential drawback is the lack of academic research and consensus behind the specific composition of the DESI, and the composite index consequently might measure too little or too much. Nevertheless, among the sparse availability of literature assessing the validity of the DESI dimensions, we do find some interesting results. Stavytskyy et al. (2019) conclude that increased consumption advances an economy's digital services and that this in turn combats unemployment, but this is a slow process as their findings indicate that an increase in the composite DESI index is highly determined by its preceding trend. Bánhidi et al. (2020) perform a partial correlation analysis of the dimensions' linear relationships to determine causality between the DESI's policy areas, and find that its five dimensions can be reduced to two main independent components: connectivity and human capital. This coincides with our earlier premise that the ability to access the Internet is an absolute requirement in order to exploit the opportunities offered through digitalization, but that (digital) human capital is crucial in determining the success of those possibilities.

Table 2: The five main policy areas which envelop the Digital Economy and Society Index.

Connectivity	Fixed broadband take-up, fixed broadband coverage, mobile broadband, and broadband prices.
Human capital	Internet user skills and advanced skills.
Use of internet	Citizens' use of internet services and online transactions.
Integration of digital technology	Business digitisation and e-commerce.
Digital public services	e-Government.

Out of the remaining three DESI dimensions, (1) the use of internet services and online transactions depend on the level of connectivity and the quality of human capital, (2) the integration of digital technology is related to human capital only, and (3) the provision of qualitative digital public services results from the level of integration of digital technology, and hence is indirectly determined by basic and advanced Internet user skills. The earlier findings of Bánhidi et al. (Bánhidi et al., 2020) confirm our hypothesis that the combination of stable and consistent broadband infrastructure with investments in human capital regarding Internet user skills and advanced skills are the two principal components determining the overall outcome of digitalization and shaping the path of the other dimensions. Accordingly, we consider the connectivity dimension and the human capital dimension as two important primary objectives in achieving balanced growth through digitalization, and we identify the most relevant indicators pertaining to rural areas in table 3. Similarly, the use of internet, the integration of digital technology, and the availability of digital public services together form three secondary objectives for which table 3 also indicates the most relevant indicators for rural areas specifically. The rural relevance for the two primary objectives is indicated in blue, while the relevance for the three secondary objectives is indicated in green. This reduces the set of 37 indicators to 28 indicators that are expected to either directly or indirectly impact rural development both from consumption and production perspectives. This set can be further reduced by having a thorough look at the remaining indicators. On the one hand, eliminating measures that are only indirectly relevant from a rural perspective, and, on the other hand, combining several indicators if they measure a common and simplified variable. Future regional data collection would allow us to shed further light on the validity of these reductions.

The connectivity dimension can firstly be transformed into two principal components, fixed broadband and mobile broadband, within which we distinguish between take-up and coverage amongst different download and upload rates. Moreover, as broadband take-up depends on broadband coverage, we suggest employing broadband coverage as the sole primary indicator for the rural connectivity dimension from the perspective of an urban-rural digital divide.

Table 3: The different indicators of the DESI and their corresponding NUTS levels.

Dimension	Sub-dimension	Indicator	Deepest NUTS level	Rural relevance
1 Connectivity	1a Fixed broadband take-up	1a1 Overall fixed broadband take-up	0	++
		1a2 At least 100 Mbps fixed broadband take-up	0	+
	1b Fixed broadband coverage	1b1 Fast broadband (NGA) coverage	3	+++
		1b2 Fixed Very High-Capacity Network (VHCN) coverage	3	+++
	1c Mobile broadband	1c1 4G coverage	0	+++
		1c2 Mobile broadband take-up	0	++
		1c3 5G readiness	0	
	1d Broadband price index	1d1 Broadband price index	0	
2 Human capital	2a Internet user skills	2a1 At least basic digital skills	0	+++
		2a2 Above basic digital skills	0	++
		2a3 At least basic software skill	0	+
	2b Advanced skills and development	2b1 ICT specialists	0	+
		2b2 Female ICT specialists	0	
		2b3 ICT graduates	0	
3 Use of Internet services	3a Internet use	3a1 People who never used the internet	0	
		3a2 Internet users	0	+++
	3b Activities online	3b1 News	0	+
		3b2 Music, videos, and games	0	+
		3b3 Video on demand	0	+
		3b4 Video calls	0	+
		3b5 Social networks	0	++
		3b6 Doing an online course	0	+
	3c Transactions	3c1 Banking	0	+
		3c2 Shopping	0	++
		3c3 Selling online	0	++
4 Integration of digital technology	4a Business digitisation	4a1 Electronic information sharing	0	+++
		4a2 Social media	0	+++
		4a3 Big data	0	+++
		4a4 Cloud	0	+++
	4b e-Commerce	4b1 SMEs selling online	0	++
		4b2 e-Commerce turnover	0	++
		4b3 Selling online cross-border	0	
5 Digital public services	5a e-Government	5a1 e-Government users	2	++
		5a2 Pre-filled forms	0	
		5a3 Online service completion	0	
		5a4 Digital public services for businesses	0	+
		5a5 Open data	0	

Internet user skills are still equally relevant from a rural perspective, of which the possession of at least basic digital skills is by far the most important from a consumption stance and acts as a hypernym for the other DESI indicators related to digital skills. These individuals are broadly identified as being capable of using the Internet for information gathering, communication purposes, problem solving, and utilising software for content creation based on their activities of the past five months prior to the data collection surveys. The three indicators representing individuals' advanced skills and development are either less relevant from a rural perspective (female ICT specialists) or do not directly contribute to rural development (ICT graduates). Regional ICT graduates do not contain any information on their employment status. Either they utilize their ICT expertise in formal regional sectors (and then this information is contained in the ICT specialists indicator) or they do not, in which case their presence is reflected in the Internet user skills dimension. From this perspective, it is important to only hold on to those indicators for which there cannot be any doubt regarding the individuals' rural presence. Therefore, the human capital dimension can be reasonably reduced to individuals' possession over at least basic digital skills, and the presence of ICT specialists.

The large set of measures indicating the specific use of Internet services can be greatly reduced due to its large correlation with the connectivity dimension and the human capital dimension (Bánhidi et al., 2020). The importance of the number of Internet users is evident, and additionally contains information on broadband take-up. The large majority of digital platforms related to news reporting, the purchasing or streaming of entertainment media, and participating in online courses, offer their services nationwide, and are therefore of no more particular interest from a rural perspective. Their usage entirely depends on the quality of the prevailing broadband infrastructure and the individuals' capability to use them, i.e. the connectivity dimension and the human capital dimension. The prevalence of the transactions category, on the other hand, depends on different transaction and transportation costs related to geographical proximity, and are therefore relevant to maintain. Social networks can play a vital role in significantly reducing some of these costs.

The integration of digital technology is an incredibly relevant, technical, and complex category which warrants its own thorough analysis and is therefore left almost entirely untouched, while the provision of digital public services is reduced to a general indicator measuring the number of e-Government users.

This exercise leads to a rural DESI comprising 19 key indicators. Table 4 summarises.

2.3. Data collection

The first-stage objectives result in five key policy areas in digitalisation and 1348 NUTS level 3 regions. In order to present a descriptive overview of Europe's progress and to develop causal mechanisms linking this progress to the regions' socioeconomic performance, we first need consistent and accurate data.

2.3.1. Secondary data

In table 4, we list the deepest NUTS level for which secondary data is immediately available. With the exception of data on fixed broadband coverage (1a) and e-Government users (5a1), all DESI indicators are only available at the national level (NUTS 0). Out of these three remaining indicators, only data on fixed broadband coverage can be retrieved at NUTS level 3. Consequently, only the connectivity dimension of the DESI immediately lends itself for regional assessment.

Data on fixed broadband coverage across Europe was purchased from Point Topic and contains annual information on household access to connectivity speeds of at least 2 Mbit/s, 30 Mbit/s, and 100 Mbit/s respectively[4]. For each NUTS level 3 region, the share of households with access to these different rates is available. The collection of data on these variables started in 2011, and Eurostat's NUTS classification has thenceforth undergone three major updates (in 2013, 2016, and 2021)[5]. Each update contained five different kinds of revisions to the European regions: mergers (NUTS level 3 regions are combined, i.e. their common administrative borders vanish but the external borders remain), splits (NUTS level 3 regions are split up, i.e. common administrative borders are created within existing external borders), boundary shifts (external administrative borders are altered), recodes (NUTS level 3 regions are relabelled), and discontinuations (NUTS level 3 labels are removed). These five actions are often intertwined. However, the annual extension of the available data on fixed broadband coverage was often not fully adapted to changes in the NUTS classification, and the resulting data set represented a mixture of NUTS level 3 labels from the 2010 classification, 2013 classification, and 2016 classification. The mergers were easily dealt with, as we also possessed the absolute demographic data on which the broadband shares relied. The relevant shares were transformed into absolute household data using the accompanying demographics, and then merged together before reconverting to shares, considering demographic evolutions over time. This simple method revealed inconsistencies over time in some of the available data for some regions in Finland,

[4] Source: http://point-topic.com/.

[5] Source: https://ec.europa.eu/eurostat/web/nuts/history.

Germany, and Portugal. Around 80 out of 10784 observations were affected and these entries had to be removed from the data set. Splits, on the other hand, required a different approach. Fortunately, this only affected 12 regions, and they were all situated in Greece which comprises 51 NUTS level 3 regions. One example of such a split is Attica, which made up a single NUTS level 3 region but was then divided over 7 different regions (Northern Athens, Western Athens, Central Athens, Southern Athens, Eastern Attica, Western Attica, and Piraeus). Since all of our data from 2011-2018 was available for Attica and the other pre-split regions as a whole (and external borders are unaffected in the case of NUTS level 3 splits), there was no need to remove these entries from the data set. Adjusting the provided data set to comply with the boundary shifts was not so straightforward. Vectorisation in QGIS, layering NUTS 2010, NUTS 2013, and NUTS 2016 shapefiles, was considered but rejected, as this method does not take demographic centres of gravity into account. Additionally, it distorted total population and household values causing them not to add up consistently anymore. Instead, population numbers of villages and cities involved in the boundary shifts were considered. If the 'population exchange' at the external borders made up less than 5% of the total population in every individual region involved before conversion, less than 5% of the total population in every individual region involved after conversion, and the coverage data before conversion differed within a margin of 10 percentage points, the original coverage data were maintained after the boundary shifts, and the regions were simply recoded. Under these circumstances, the potential effects of boundary shifts on the regions involved were negligible. Albeit arbitrary at first glance, it is worth noting that almost all boundary shifts either fell way below the 5% population condition or were way larger. Therefore, the methodology under these conditions was deemed appropriate. Demographic data provided by Point Topic were used to determine population numbers before conversion, while Eurostat data were used to determine population quantities after conversion. Finally, some regions were represented on multiple occasions within the same data set under different labels. R was applied to discover these double representations, and, depending on the exact cause of the overlap, one of the above methodologies was applied to the corresponding time period.

2.3.2. Primary data

The secondary data analysis revealed a crucial weakness with regards to a comprehensive and general study of rural digitalisation: a significant lack of usable data. There is no freely available European data at NUTS level 3 for our rural DESI, and as far as commercially available data goes, only NUTS level 3 data for the connectivity dimension can be retrieved, more specifically only concerning fixed broadband coverage. 17 out of the 19 rural DESI indicators cannot be immediately quantified, and consequently, without intensively collecting primary data, we can only describe and explain one fragment of the story. Primary data collection is unequivocal to painting the entire picture.

However, collecting data on even a single rural indicator covering all of Europe requires a long, exhaustive, and collective effort which requires transboundary consistency in its measurement. A temporary solution would be to conduct separate country-specific analyses. Not only does this allow for increased flexibility in measurement consistencies, but primary data collection is also more feasible, and some institutions already provide additional data within their national borders. Although the accuracy can be improved through the inclusion of country-specific elements, gaining a general and comparative impression would not yet be possible without consistent measurement.

We can therefore conclude that future investigations into this topic should be twofold: there should be a focus on the validity of the rural indicators – which is yet a cause of uncertainty and disputes at more aggregated levels – and on the disaggregation of further data collection. The latter hereby lends crucial assistance to the former.

Table 4: The different indicators of the rural DESI and their corresponding NUTS levels.

Dimension	Sub-dimension	Indicator	Deepest NUTS level
1 Connectivity	1a Fixed broadband coverage	1a1 Connectivity rates of at least 30 Mbit/s	3
		1a2 Connectivity rates of at least 100 Mbit/s	3
	1b Mobile broadband coverage	1b1 4G coverage	0
		1b2 5G coverage	0
2 Human capital	2a Internet user skills	2a1 At least basic digital skills	0
	2b Advanced skills and development	2b1 ICT specialists	0
3 Use of Internet services	3a Internet use	3a1 Internet users	0
	3b Activities online	3b1 Social networks	0
	3c Transactions	3c1 Banking	0
		3c2 Shopping	0
		3c3 Selling online	0
4 Integration of digital technology	4a Business digitisation	4a1 Electronic information sharing	0
		4a2 Social media	0
		4a3 Big data	0
		4a4 Cloud	0
	4b e-Commerce	4b1 SMEs selling online	0
		4b2 e-Commerce turnover	0
			0
5 Digital public services	5a e-Government	5a1 e-Government users	2

3. Fixed broadband coverage in European rural areas

Due to the data limitations discussed in the previous chapter, the remainder of this report will primarily focus on the connectivity dimension of the European Commission's Digital Economy and Society Index (and our reduced rural DESI). The NUTS level 3 data was purchased from Point Topic and covers the evolution in fixed broadband coverage from 2011 up until 2018 in the former EU28[6]. Fixed broadband coverage is defined as the share of households per region with access to fixed broadband networks capable of realistically achieving download speeds of at least 2 Mbps, 30 Mbps, and 100 Mbps.

Although the regional data unavailability of the remaining four DESI dimensions hinders the construction of a workable Rural Digitisation Index, this need not be an obstacle to conducting an informative rural assessment of digitalisation in Europe. Broadband coverage is a *condicio sine qua non* for the development of the other DESI dimensions, and therefore can be partially regarded as a one-directional proxy for these policy areas. Countries performing weakly when it comes to broadband coverage, can also be expected to perform poorly in the other dimensions. Bánhidi et al. (Bánhidi et al., 2020) easily verified this assumption at the national level and concluded that connectivity is complemented in this decisive role by the level of digital human capital. Nevertheless, the several indicators comprised by the DESI's human capital dimension also benefit from (and require) improved broadband infrastructure.

3.1. The Digital Single Market

The creation of a Digital Single Market (DSM) was listed among the ten priorities of the mandate of the 2014-2019 Juncker Commission. A strategy to develop the DSM was adopted in May 2015, and aims to ascend the free movement of people, services, and capital into the virtual realm. This will ensure that both businesses and individuals can access and engage in online activities, whilst maintaining fair competition, with a strong enforcement of consumer and personal data protection. As mentioned earlier, an absolute prerequisite for this achievement is the provision and take-up of very high-capacity networks (VHCN) to successfully diffuse the use of products, services, and applications as outlined in the Digital Single Market. In the spirit of this acknowledgement – and in

[6] At the time of writing, the European Union comprises 27 Member States. Croatia became the twenty-eighth member in 2013, while the United Kingdom have officially withdrawn their membership in 2021. In this section, we refer to EU28 as the twenty-eight Member States during 2018.

support of the DSM – the European Commission committed to providing every European household with access to broadband speeds of at least 30 Mbps by 2020, and half of European households with connectivity rates of more than 100 Mbps.

In September 2016, the Commission expanded these broadband objectives by announcing their strategy on Connectivity for a European Gigabit Society. The three new main strategic objectives for 2025 are:

- Gigabit connectivity for all of the main socioeconomic drivers.
- Uninterrupted 5G coverage for all urban areas and major terrestrial transport paths.
- Access to connectivity rates of at least 100 Mbps for all European households.

In this section, we take stock of the digital connectivity of European households, specifically rural households, and a comparison across Europe is shown. We also illustrate the progress towards the achievement of the European Union's broadband objectives.

3.2. The gap between urban, intermediate, and rural areas

Significant progress has been made over the past couple of years regarding the objectives defined in the Digital Agenda for Europe. In 2016, 51% of European households had access to broadband connectivity rates of at least 100 Mbps, surpassing its benchmark with a 4-year margin. Despite significantly higher growth rates, the goal of providing every single European household with 30 Mbps had not yet been reached as of 2018. Hitting this target requires the identification of specific problem areas which cannot be determined by the aggregate case depicted in Figure 2. As it is suspected that lower connectivity is related to geographical features, in the following sections, a disaggregated analysis of European regions by remoteness is provided.

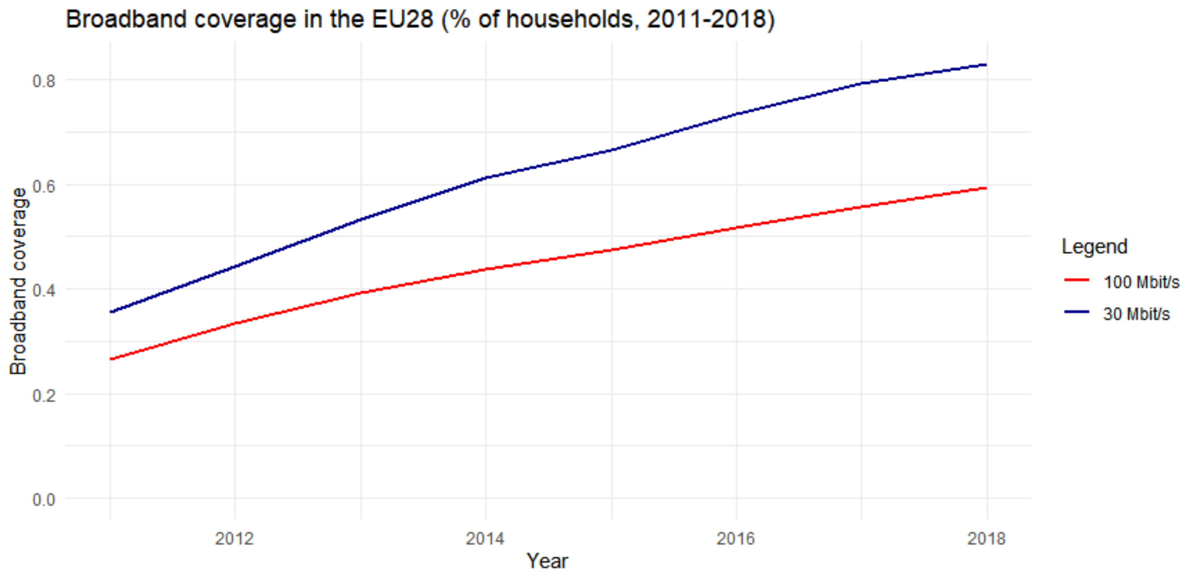

Figure 2: Broadband coverage in the EU28 (2011-2018) as expressed by the share of households enjoying high-speed broadband access of at least 30 Mbps and 100 Mbps, respectively.

Figures 3 and 4 disaggregate the time series above according to the previously discussed urban-rural NUTS 3 typology. In each figure, the differences in broadband coverage between rural/intermediate and urban areas are depicted. The announcement of the Digital Single Market and its subsequent broadband objectives had immediate positive effects on Europe's 30 Mbps network coverage. European rural areas had always lagged behind relative to their urban and intermediate counterparts, and this coverage gap remained stable around its peak until 2015 prior to the introduction of the DSM strategy. Afterwards, rural areas began to catch up with urban regions in terms of network coverage as measured by the proportion of households having access to high-speed broadband of at least 30 Mbps. Intermediate regions were already closing down the gap since 2012 but saw a significant acceleration of this digital convergence process after the DSM adoption.

However, the divide remains large. While urban areas were well on their way to reaching the objective of 100% household coverage in 2020 (91% as of 2018), only an estimated 65% of rural households enjoyed access to broadband speeds of at least 30 Mbps in 2018. Although the circumstances in rural areas concerning high-speed access of no less than 100 Mbps seem even less favourable (the difference with predominantly urban regions became larger after the DSM announcement), rural areas were closer to reaching their 2020 target compared to the 30 Mbps objectives. In 2018, 40% of households in rural regions were covered by these high-speed networks.

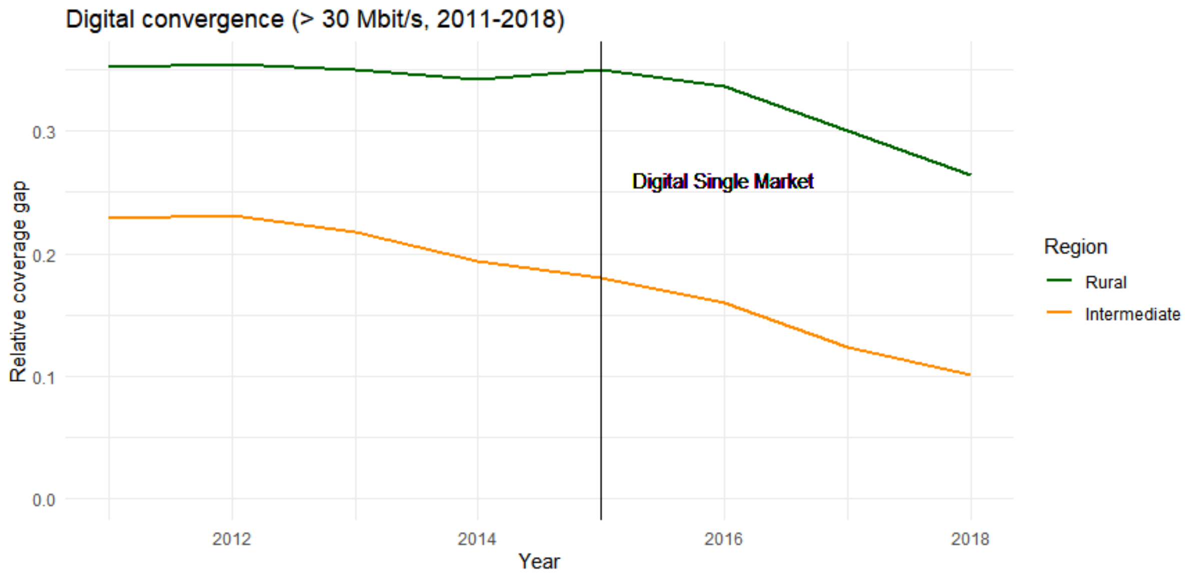

Figure 3: The broadband coverage gap (network speeds > 30 Mbps) in predominantly rural and intermediate EU28 regions, as expressed by the percentage-point difference in aggregate household coverage towards predominantly urban areas (2011-2018).

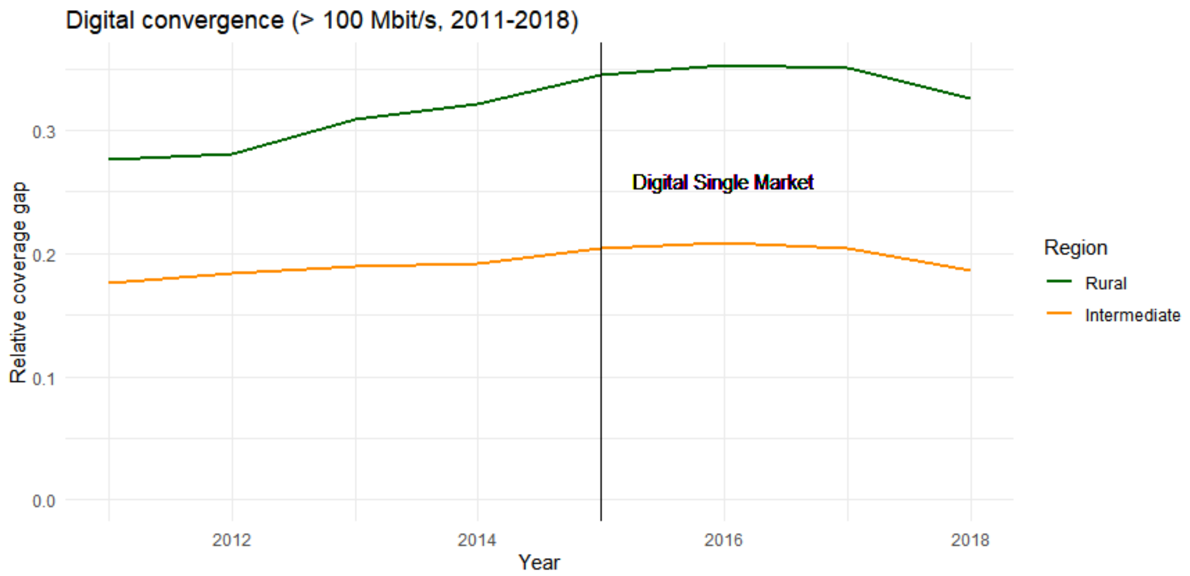

Figure 4: The broadband coverage gap (network speeds > 100 Mbps) in predominantly rural and intermediate EU28 regions, as expressed by the percentage-point difference in aggregate household coverage towards predominantly urban areas (2011-2018).

3.3. Broadband coverage in rural areas

Supplying broadband coverage in remote areas is markedly less cost-efficient for network providers but plays an important role in preventing a digital divide and reducing socioeconomic externalities resulting from remoteness. Internet connectivity benefits rural businesses by improving productivity, reducing costs, and expanding access to supplier networks, and it supports rural communities by facilitating the delivery of goods and services – an important counterbalance against rural-urban poverty gaps[7]. High-speed broadband access also enhances the development of sustainable agriculture through smart farming.

A disaggregated illustration of the rural divide is given in Figure 5, which represents the evolution of broadband coverage (> 30 Mbps) in all 28 EU Member States per NUTS 3 region. There was a tremendous advancement between 2011 and 2018. While most of the within-country variation can be explained by the distinction between urban and rural regions, there are also significant between-country variations at the more aggregate level. Analysing both sources of disparity can help supranational institutions, and national and local governments, pinpoint lagged regions more accurately. This facilitates cooperation, expedites the allocation of funds, and encourages the establishment of public-private partnerships through risk-reduction and increased efficiency.

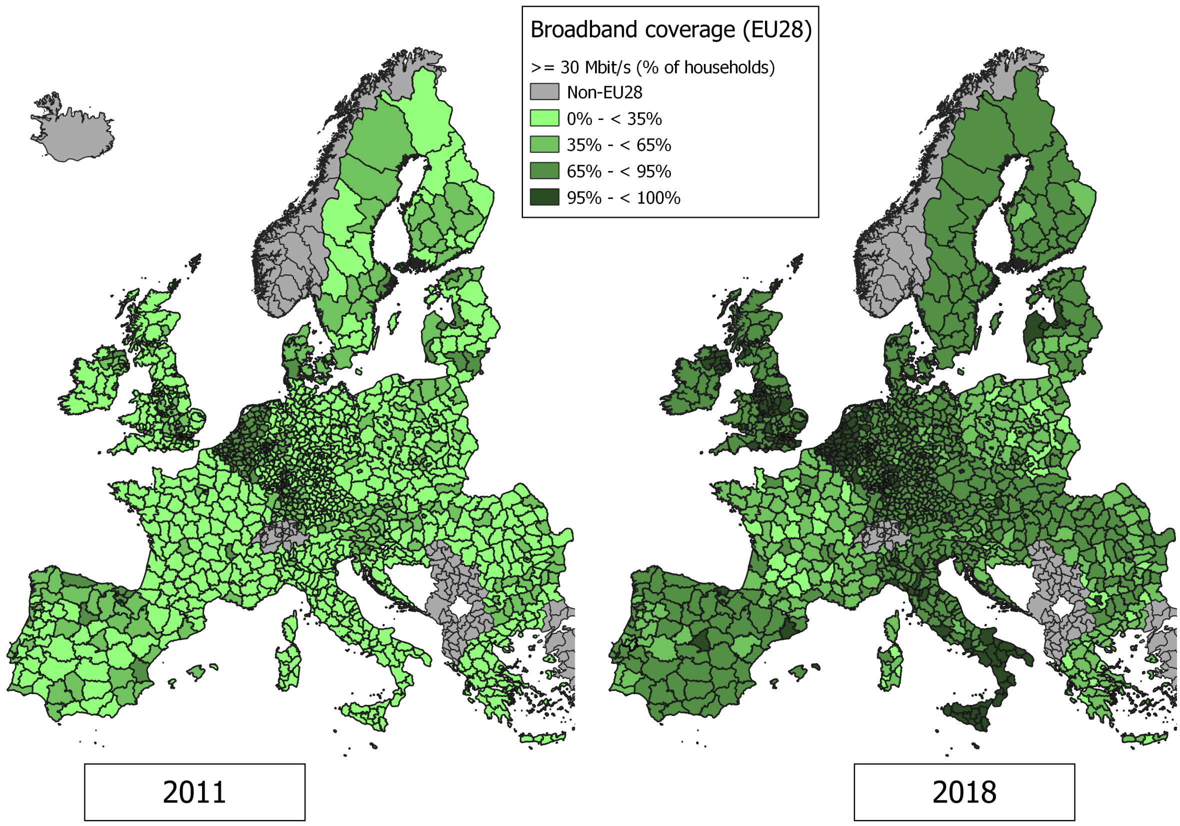

Figure 5: Broadband coverage in the EU28 (2018), as expressed by the share of households with access to connectivity speeds of at least 30 Mbps.

[7] See Bernard (2019) for an extensive overview of rural-urban poverty gaps in European countries.

An illustration of the within- and across-country variation is given by Figure 6, where all NUTS 3 regions in Germany, Italy, Luxembourg, and the UK – four countries with similarly large population densities – are grouped. Rather than classifying regions as either urban or rural, this graph uses population grid cells to estimate the share of rural households in every region, which serves as an indicator of ruralisation per region. This share is mapped against the percentage of households being able to access broadband speeds of at least 100 Mbps. The negative relationship between ruralisation and broadband coverage is clearly present, but more interesting are the large differences within and between countries despite sharing similar population densities. These differences are present at all levels of ruralisation and are crucial for policymakers to identify.

Figure 7 represents the same exercise across Greece, Spain, France, and Hungary – countries with a similarly low population density. The same conclusions can be drawn.

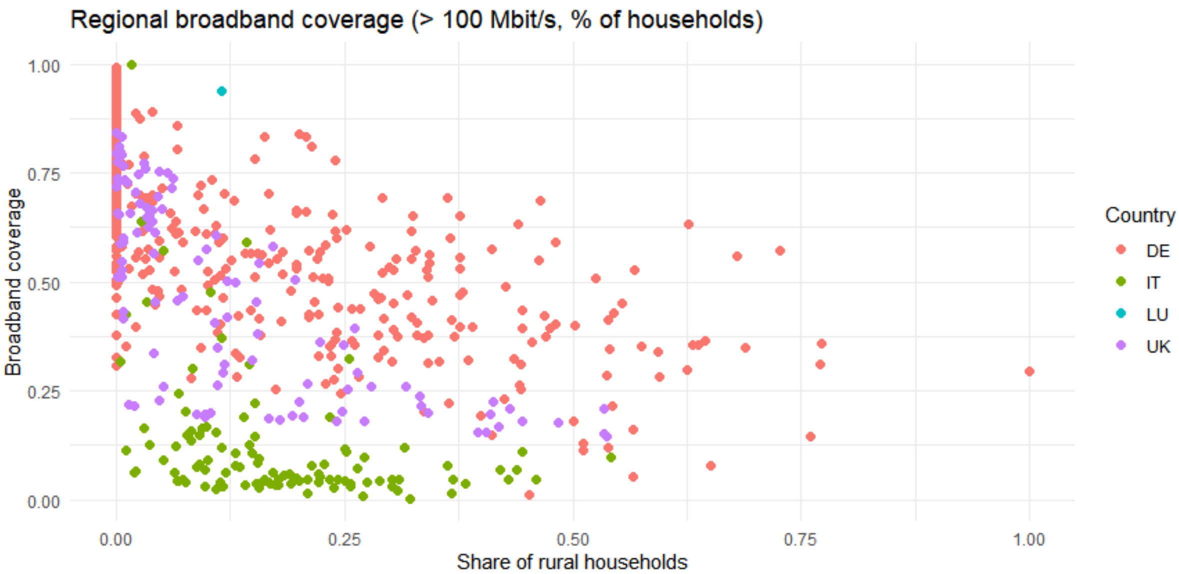

Figure 6: The share of rural households within specific NUTS 3 regions in Germany, Italy, Luxembourg, and the UK, and their respective broadband coverage (100 Mbps). The urban-rural distinction is further deepened by utilising population grid cells to estimate the share of rural households more accurately in every region. As a result, all NUTS 3 regions are included.

A strategically coordinated push could lift these regions out of their digital poverty traps. Europe will need to define a structural solution for the continuous lagged digital state of rural areas to be on track for its 2025 broadband commitments. Although rural regions seem to be finally catching up in terms of 30 Mbps, the digital divide with regards to high-speed broadband access of at least 100 Mbps continued to widen until 2017. In this regard, the definition of the 2025 broadband objectives is not more ambitious than their predecessors. On the one hand, it is explicitly stated that uninterrupted 5G coverage is a priority only in urban areas. On the other hand, when access to 100 Mbps networks will eventually become the norm in rural Europe, it can be expected that most of the urban areas will have already move on towards higher speeds. There seems to be a structural digital divide across broadband innovations behind the data.

Digitalisation is an increasingly rapid phenomenon, and the essential element for preventing a digital divide is to ensure simultaneous access to these latest technologies both in rural and urban areas in order to achieve inclusive regional development. The identification of the specific lagging regions is imperative.

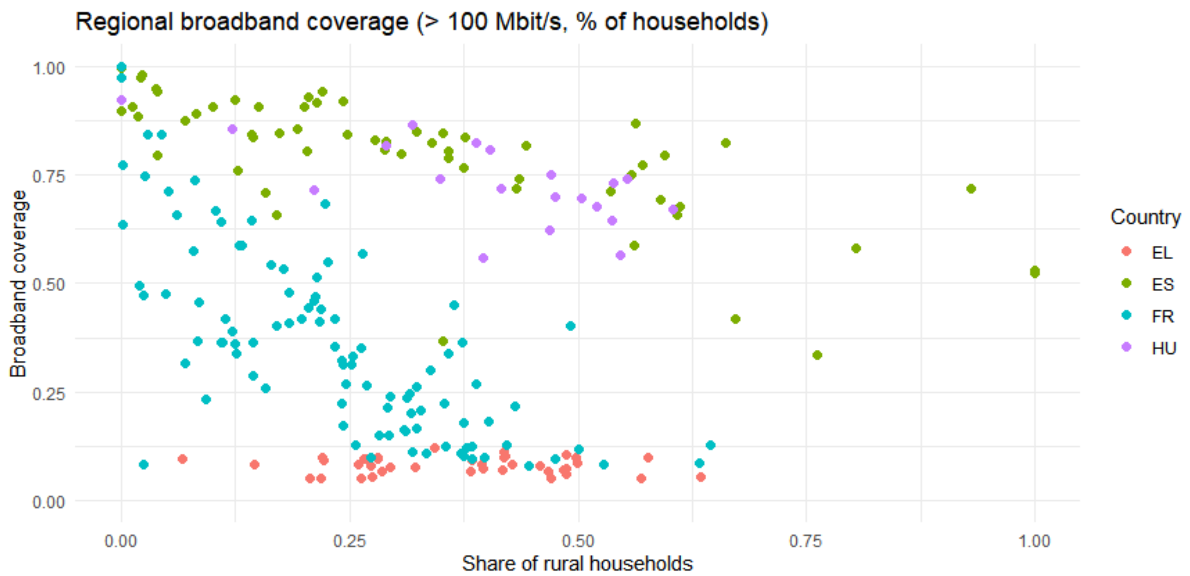

Figure 7: The share of rural households within specific NUTS 3 regions in Greece, Spain, France, and Hungary, and their respective broadband coverage (100 Mbps). The urban-rural distinction is further deepened by utilising population grid cells to estimate the share of rural households more accurately in every region. As a result, all NUTS 3 regions are included.

4. Economic growth and broadband access

This chapter takes our previous examination of regional broadband access between 2011 and 2018 across all 27 Member States of the European Union as well as the United Kingdom and relates its provision to economic growth. Section 4.1 gives a brief overview of the literature on the relationship between economic growth and digitalisation against the backdrop of rapid technological innovation. Armed with this contextual understanding and the preceding analysis, we define the quantitative model in section 4.2. Section 4.3 thoroughly discusses the results and performs some crucial robustness checks. Finally, section 4.4 concludes.

4.1. Telecommunications and economic growth

Studies on the contribution of digitalisation to countries' aggregate economic performance succeed from a vast body of literature on telecommunications technologies. Although the 19th-century introduction of the electrical telegraph marked the beginning of the revolution in telecommunications, its role as a determinant of economic growth was largely ignored by neoclassical economists (Phillips, 2000). The relatively small capital formation, inaccurate data, and underdeveloped statistical tools and techniques hindered mainstream economic analysis, and it was only picked up seriously through the work of Field (1992) and others when institutional economics offered a more suitable framework to observe the innovation's historical impact on economic growth and its social rate of return.

Consequently, telegraph studies relying on quantitative observation methods are scarce, if not inexistent. In the final decades of the 20th century, many of the initial shortcomings and obstacles preventing quantitative analyses of the telegraph's potential role in stimulating economic growth were lifted. Quantitative methods vastly improved, and researchers gained access to more accurate historical national and regional accounts. However, the telegraph as a telecommunications innovation was long outdated and its competitive advantage exhausted. It had been dethroned by the telephone, and with the latter's widespread diffusion came the firm conviction that an extensive telecommunications infrastructure was a *condicio sine qua non* for economic development and, more broadly, progress. From 1970 onwards, public policy and private enterprise resorted to closing down market gaps by ensuring the prevalence of telecommunications networks (Gómez-Barroso & Marbán-Flores, 2020a).

Yet, extensive academic interest in the analytical impact of telecommunications infrastructure and investments on economic growth was put off until the 1990s, and initially strongly revolved around issues of reverse causation. A significant correlation was evident, and instead debates on the exact nature of the relationship took centre stage. Cronin et al. (1991) find evidence for a bidirectional causal relationship between economic growth and telecommunications investment. This two-way relationship is confirmed by Madden and Savage (1998) for main telephone lines, and later by Lam and Shiu (2010) for mobile telecommunications. However, there seems to be no general consensus regarding this mutual precedence. Dutta (2001) adopts a Granger approach and concludes for both industrialised and developing countries that there is strong evidence for causality running from telecommunications to economic activity, while there is little evidence for causality in the opposite direction. Chakraborty and Nandi (2011) find a unidirectional causal effect of economic activity on telecommunications adoption in the short run, but a bidirectional causal effect in the long term.

It is necessary to point out that these mixed results have been established in a diverse research environment including a multitude of diverse countries, regions, and technologies. Therefore, it is not unreasonable to suggest that the exact nature of the relationship depends on the intrinsic values and attributes of the telecommunications innovation and the current development status of a certain country or region.

As the first decade of the 21st century progressed, focus on telecommunications *sensu stricto* faded and progressively made way for empirical investigations into broadband and mobile communications. Gómez-Barroso and Marbán-Flores (2020b) point to the non-linear relationship between telecommunications and real GDP growth in order to explain the declining research interest. Broadband, whether fixed or wireless, acts as a gradual replacement technology for telecommunications and became the defining variable that influences contemporary economic growth. This non-linearity for investments in strict telecommunications infrastructure is confirmed by Torero et al. (2006) for a global dataset comprising 113 countries, and by Datta and Agarwal (2004) for the OECD economies. The existence of a threshold level after which additional investments yield diminishing returns is also found to be inherent in the 21st-century telecommunications technologies. Ghosh (2016) uncovers evidence for a non-linear relationship between cellular penetration and income for 15 MENA countries, while Waverman et al. (2005) further substantiate these results for a larger set of developing countries.

These results are in accordance with the Schumpeterian approach to endogenous growth theory that views continuous technological progress through quality or productivity improvements rather than capital accumulation as the only means to eliminate diminishing returns and sustain long-term economic growth (Barro & Sala-i-Martin, 2004). Inherent in Schumpeterian models of endogenous growth is the idea that technological improvements induce new goods and services that replace previous innovations. Schumpeter (1942) famously termed this disruptive process as *creative destruction*. The broad history of telecommunications, from the electrical telegraph to the contemporary 5G networks, serves as a testimony to these models.

4.2. Model

Recent empirical literature investigating the relationship between telecommunications investments and economic growth more frequently starts from the premise that economic growth and technological progress are endogenous. As discussed earlier, many authors find a reverse causality between telecommunications and economic growth, and significant issues with endogeneity often arise (Chakraborty & Nandi, 2011; Cronin et al., 1991; Dutta, 2001; Madden & Savage, 1998). As a result, there has been a surge in publications using advanced time series and panel data techniques to address these issues. One of the more commonly used estimators is the first-differenced generalised method of moments (GMM) to estimate dynamic panel data models (Arellano & Bond, 1991; Holtz-Eakin et al., 1988). In these estimators, unobserved individual fixed effects are removed by taking first differences, and then the deeper lags in levels are used as instruments to estimate the equations. This estimator not only allows for reverse causality, but also for measurement error and omitted variables – other common problems with estimating growth equations. However, the first-differenced generalised method of moments typically does not yield plausible results in cross-country growth regressions as economic growth measured in output tends to be highly persistent, resulting in weak instrumental variables and, subsequently, large finite sample biases (Bond et al., 2001). The system generalised method of moments estimator developed by Arellano and Bover (1995) and Blundell and Bond (1998) offers superior properties in this context. Due to our limited time period ($T = 8$), we follow this latter approach.

Insights from Schumpeterian approached in endogenous growth theory and earlier empirical work led us to estimate the following dynamic steady-state equation, based on Myovella et al. (2020) and Czernich et al. (2011):

$$GRTH_{it} = \alpha_1 GRTH_{i,t-1} + a_2 B_{it} + \alpha_3 B_{it}^2 + \boldsymbol{X}'_{it}\beta + \delta_t + \varepsilon_{it} \quad (1)$$

where i indexes regions and t indexes time. Individual time-invariant effects have been eliminated after taking first-differences. The rate of growth of real GDP per capita ($GRTH$ – in purchasing power parities) is affected by its preceding growth, the provision of high-speed broadband access B_{it}, and a number of control variables captured by the vector $\boldsymbol{X}'_{it}$, which includes population growth, data on trade openness TOP_{it}, government consumption expenditure EXP_{it}, and gross domestic investments I_{it}. Moreover, we include a variable measuring lagged GDP per capita ($GDPPC_{i,t-1}$) to test for convergence. A negative coefficient for lagged real GDP per capita (in purchasing power parities) indicates convergence, as higher levels of past GDP more effectively slow down the economy through lower subsequent growth. We expect a positive coefficient for the provision of high-speed broadband access, as we hypothesise that the extension of stable broadband infrastructure is a prerequisite for the further development of the rapidly changing digital economy central to life in the 21st century. We conduct this regression for both 30 Mbit/s connectivity rates and 100 Mbit/s connectivity rates. The squared broadband variable is included to test for diminishing returns to investments in high-speed broadband infrastructure – a result commonly found in all literature pertaining to telecommunications *sensu lato*. The relationship between growth and gross domestic investments is robustly positive in the existing growth literature (Datta & Agarwal, 2004), and its corresponding sign is therefore expected to be positive, while the role government consumption expenditure remains relatively uncertain. Trade openness, measured as the sum of exports and imports as a share of GDP, is expected to have a beneficial impact on economic growth.

Data at NUTS level 3 is available for all of the variables in our growth regression, with the exception of the degree of trade openness, gross domestic investments, and government consumption expenditure. Data on GDP and employment was retrieved from Eurostat, while the population data was included in our Point Topic dataset. Due to the uncertainty surrounding the role of government consumption expenditure, and the significantly robust empirical relationships in international trade theory and growth theory between trade openness and investments on the one hand, and employment growth rates on the other hand, we instead opt for NUTS level 3 data on formal sector employment as imperfect proxies for these control variables (Bernard et al., 2012).

4.3. Results and discussion

Table 5 reports the results concerning connectivity rates of at least 30 Mbit/s. Model (1) yields the regression results for the general economy, all sectors and regions combined. Model (2) shows the results for the agricultural sector, whilst still combining all regions. Finally, model (3) trims down the data to the agricultural sector and excludes all predominantly urban regions.

The provision of high-speed broadband access has a significant and positive impact on real output per capita. This is in line with the expectations based on all previous empirical analyses at the country-level. However, our results indicate a relatively weaker effect in rural areas compared to their urban counterparts. The negative and significant coefficient for the squared broadband variable confirms previous research that had found diminishing returns to scale to broadband investments. The results are also robust across all sectors and regions. The impact of fixed broadband access on real output in the agricultural industry is relatively large compared to the general economy. Full household provision implies additional gains up to 26 percentage points across all areas, and up to 16 percentage points in rural regions, perpetuating the current boom in smart farming technologies and illustrating its economic relevance. All of the coefficients yield their expected signs.

When we replace the 30 Mbit/s broadband variable with the share of households that has access to network speeds of at least 100 Mbit/s, the significant impact on economic growth disappears for the agricultural sector but remains when we consider the different economies as a whole. Contrary to the conclusions drawn from the 30 Mbit/s regression, economic growth in intermediate and predominantly rural areas benefits more from the provision of broadband infrastructure in terms of connectivity rates offering 100 Mbit/s and up as opposed to the more urbanised regions. Given the presence of diminishing returns to scale for broadband infrastructure and the larger urban-rural digital divide in terms of 100 Mbit/s, these results align better with our expectations as opposed to the 30 Mbit/s outcome. One possible explanation could be found within urban and rural differences regarding the specific utility and purpose of digitalization on both the consumption and production sides of the economy. Further research would benefit from investigating these urban-rural differences pertaining to digital consumption and allocation.

Table 5: The effects of fixed broadband coverage on economic growth (connectivity rates offering at least 30 Mbit/s).

	Independent variable :			
	GRTH			
	Model (1)	Model (2)	Model (3)	Model (4)
	All sectors	All sectors	Agriculture	Agriculture
	All regions	Non-urban regions	All regions	Non-urban regions
GRTH(*t*-1)	-0.0781***	-0.0974***	-0.1796***	-0.2248***
	(0.0204)	(0.0236)	(0.0292)	(0.0378)
GDPPC (*t*-1)	-0.0000***	-0.0000***	-0.0000*	-0.0000**
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Broadband (30 *Mbit/s*)	0.0635***	0.0620***	0.2611***	0.1626**
	(0.0127)	(0.0140)	(0.0634)	(0.0765)
Broadband squared	-0.0494***	-0.0471***	-0.2460***	-0.1697**
	(0.0110)	(0.0124)	(0.0569)	(0.0714)
Population growth	-0.4979***	-0.6640***	0.2278	0.3894
	(0.1029)	(0.1009)	(0.3661)	(0.3168)
Employment rate	0.0245***	0.0254***	0.0774**	0.0892**
	(0.0057)	(0.0067)	(0.0354)	(0.0347)
Employment growth	0.5680***	0.4977***	-0.3100	-0.2340
	(0.0670)	(0.0808)	(0.3252)	(0.3076)
Observations	1348	985	1348	985
Sargan test p-value	0	0	0	0
AR(1) p-value	0	0	0	0
AR(2) p-value	0.1246	0.2156	0	0
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table 6: The effects of fixed broadband coverage on economic growth (connectivity rates offering at least 100 Mbit/s).

	Independent variable :			
	GRTH			
	Model (1)	Model (2)	Model (3)	Model (4)
	All sectors All regions	All sectors Non-urban regions	Agriculture All regions	Agriculture Non-urban regions
GRTH(*t*-1)	-0.0470*	-0.0671**	-0.0245***	-0.0225***
	(0.0209)	(0.0239)	(0.0109)	(0.0145)
GDPPC (*t*-1)	-0.0000***	-0.0000***	-0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Broadband (100 *Mbit/s*)	0.0296**	0.0458***	-0.0379	0.0279
	(0.0108)	(0.0122)	(0.0483)	(0.0560)
Broadband squared	-0.0220*	-0.0370**	0.0284	-0.0341
	(0.0108)	(0.0129)	(0.0482)	(0.0606)
Population growth	-0.5832***	-0.7162***	0.9180**	1.3500***
	(0.1041)	(0.0976)	(0.3065)	(0.2747)
Employment rate	0.0265***	0.0245***	0.0449	0.0902**
	(0.0060)	(0.0068)	(0.0332)	(0.0324)
Employment growth	0.5573***	0.4886***	-0.3124	-0.2638
	(0.0651)	(0.0766)	(0.3557)	(0.3217)
Observations	1348	985	1348	985
Sargan test p-value	0	0	0	0
AR(1) p-value	0	0	0	0
AR(2) p-value	0.0760	0.1500	0	0
Note:	*p<0.1; **p<0.05; ***p<0.01			

4.3.1. Discussion

Our regional investigation yields empirical evidence in support of accelerating the efforts to narrow down the urban-rural digital divide. The current broadband saturation in urbanised areas, in combination with diminishing returns to broadband provision, indicates that a significant portion of the corresponding economic benefits are yet to be reaped, both in the agricultural industry as in the global economy. Instead, telecommunications operators shifted focus to increasing network speeds in those urban areas that were already saturated at the level of 30 Mbit/s.

As broadband investments are a costly operation and rural regions are less densely populated, private incentives to guarantee high-speed broadband access are lacking. Therefore, governments inevitably have an important role to play in addressing regional digital gaps. Some regions and countries are already setting successful examples, for example Italy that managed to partially close the divide through public-private partnerships. Through these partnerships, Italy significantly caught up in 2018 while seriously falling behind in 2011, as our descriptive data in the previous chapter confirms. Such cooperation initiatives are powerful instruments to pull economies out of relative stagnation following incentive asymmetries.

Moreover, the regression results indicate a decreased upper bound of speed-related gains for the provision of broadband access in rural Europe at the one hand, and in the agricultural industry at the other hand. The reasons for this lower upper limit are manifold, and several measures to potentially shift this threshold level upwards ought to be considered. Since these weaker effects are found in two separate dimensions, this question needs to be addressed considering both different geographical features and different sectorial features. Geographically, broadband investments in rural and suburban areas have been falling behind consistently. The risks involved with delaying a balanced and inclusive broadband build-out tend to accumulate over time as network operators may only deploy innovative high-speed services if the current infrastructural equipment allows it, while equipment providers operating in competitive markets may not feel incentivised to overcome the relatively short return horizons in sparsely populated regions. Rural areas then find themselves in socially suboptimal equilibria and are less capable of profiting from broadband deployment, resulting in lower speed-related gains. Telecommunications innovations evolved into general-purpose infrastructures with significant beneficial spillovers on adopting sectors such as the health sector, manufacturing industries, financial services, electricity, and education (Gruber et al., 2014), and the disadvantages for these adopting sectors resulting from the accumulated risks implied by the digital divide are evident. In this regard, broadband communications deviate remarkably from earlier telecommunications developments *sensu stricto,* and the wider consequences for socioeconomic development and regional inequality may well extend beyond the quantifications captured within our growth regressions. The sectorial dimension poses more difficulties to conclusively account for the humble upper bound in both rural areas and the agricultural industry. The increased emergence of smart farming technologies and expansions in the digital marketing of food products might very well indicate that digitalization in rural areas and the agricultural industry is still an infant technology, and the upper bound can be pushed upwards when future interest and development in these technologies and trends increase.

We would also like to remind the reader that reverse causality is an inherent trait of the interplay between economic growth and digitalisation. This suggests that a slight additional push at well-timed occasions might get the engine temporarily running. As high-speed broadband networks accelerate economic growth, new incentives for additional investments are created through an increased reliance on digital and human capital. This not only benefits entrepreneurship, but also stimulates the development of new applications in smart farming, and more digital experts will eventually find employment in both the agricultural industry and in rural regions.

4.3.2. Robustness: the Belgian case

Our previous descriptive analysis revealed large digital dissimilarities within and across the European Member States and the United Kingdom. It is therefore an interesting exercise to conduct a smaller-scale investigation into the regional contribution of broadband provision on economic growth per capita. Belgium is one of the most densely populated Member States within the European Union, but yet comprises a balanced mix of urban, intermediate, and rural areas based on our employed typology. As a result, the 30 Mbit/s broadband provision in 2018 covers nearly the entire population, with an average of 99.6% of the households having access in urban areas, 94.3% in intermediate areas, and 83% in rural areas. The worst-performing region in 2018 still covers 80.2% of the households living within that region. In 2011, on the other hand, the rural areas in Belgium were still lagging behind quite significantly. Our data therefore captures this catching-up process, providing an interesting case study to review.

Another important reason to study broadband dynamics in Belgium is of a methodological nature. The National Bank of Belgium provides NUTS 3 data on regional imports and exports, government expenditure, and gross fixed capital formation – a major determinant of gross domestic investments. Consequently, when setting up the growth regression for Belgium, we are not dependent on the use of any imperfect proxies as opposed to the all-comprising European analysis, and instead we implement these data directly into our growth equation.

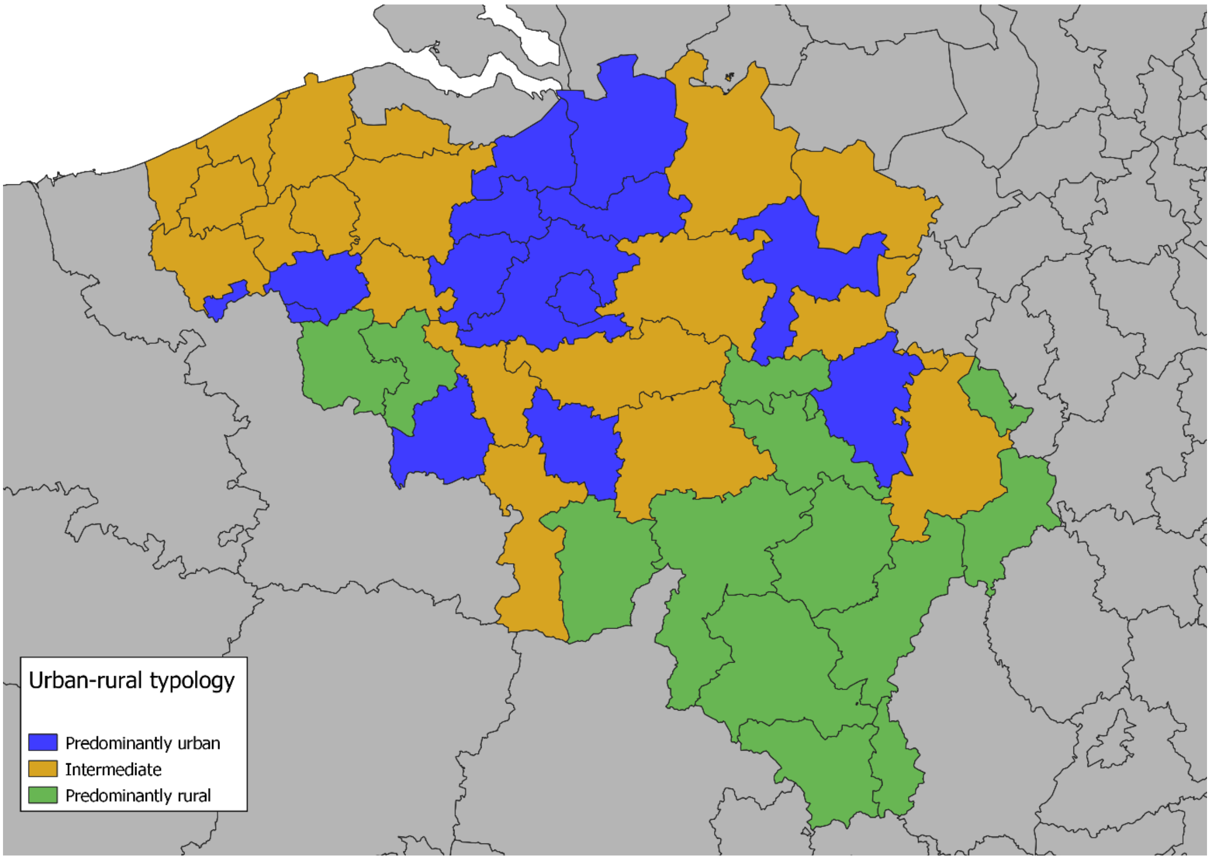

Figure 8: NUTS level 3 representation (2016) of Eurostat's urban-rural typology of Belgium.

Our regionalised cross-country growth framework based on Myovella et al. (2020) then becomes:

$$GRTH_{it} = \alpha_1 GRTH_{i,t-1} + a_2 B_{it} + \alpha_3 B_{it}^2 + \alpha_4 TOP_{it} + \alpha_5 GC_{it} + \alpha_6 GFCF_{it} + \alpha_7 POP_{it} + \delta_t + \varepsilon_{it} \quad (2)$$

where TOP measures the degree of openness to international trade reflected in the sum of regional imports and exports over GDP, affecting economic growth through productivity adjustments as a result of changes in the competitive landscape. We expect a positive coefficient for trade openness. $GFCF$ is gross fixed capital formation and GC measures government consumption expenditure. Both of these variables are expressed as a share of GDP, and they correspond with the role governments and investments play in providing infrastructure and stimulating the economy. A positive sign for both variables is to be expected, although the efficiency of the exact allocation of the fixed capital formation might distort these results. Finally, POP yields the growth rate of the population.

The inclusion of trade openness in our model leads to severe issues with near-perfect multicollinearity which results in a singular matrix containing the coefficients. Therefore, the model cannot be estimated, and we decided to remove trade openness from the regression in order to solve the multicollinearity issue and obtain regression results. In any case, the capacity of trade openness to explain regional differences in a small and densely populated country such as Belgium is doubtful.

Table 7: The effects of fixed broadband coverage on economic growth in Belgium (connectivity rates offering at least 30 Mbit/s).

	Independent variable:	
	GRTH	
	Model (1)	Model (2)
	All sectors All regions	All sectors Non-urban regions
GRTH(*t*-1)	-0.0927	-0.1785
	(0.0789)	(0.1385)
GDPPC (*t*-1)	0.0105	0.0162**
	(0.0070)	(0.0060)
Broadband (30 *Mbit/s*)	0.0175	0.1065
	(0.3993)	(0.6060)
Broadband squared	-0.0151	-0.0626
	(0.2308)	(0.3504)
Population growth	-0.9739	-1.4864
	(0.7649)	(2.7373)
Gross fixed capital formation	0.0240*	0.0158
	(0.0121)	(0.0138)
Government expenditure	0.0827	0.1821
	(0.1150)	(0.1615)
Observations	43	30
Sargan test p-value	0.0353	0.2672
AR(1) p-value	0.0116	0.0278
AR(2) p-value	0.7449	0.6300
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 7 contains the results for network coverage capable of achieving download speeds of at least 30 Mbit/s, while table 8 covers minimum rates of 100 Mbit/s. The insignificant effect of all of our control variables is a stark departure from the academic consensus deriving from a wide range of empirical research at the national level and might indicate a severe misspecification of our Belgian model. It is possible that the well-established national indicators such as gross fixed capital formation (as a representation of gross domestic investments), government consumption expenditure, and trade openness simply are not adequate at capturing regional dynamics.

It is difficult to accurately measure these variables at local levels, mostly resulting from administrative difficulties in identifying both the sources and recipients of such monetary constructs. Moreover, they might simply be incapable of explaining regional growth differences, even when measured accurately. Trade openness, for example, is usually a national affair, and one can quite believably surmise that its importance tends to decline once the geographical scope narrows – especially in small and densely populated countries such as Belgium. Generally, it is important to keep in mind that these control variables are aggregate economic constructs and their subsequent disaggregation is potentially in danger of losing its explanatory power.

Table 8: The effects of fixed broadband coverage on economic growth in Belgium (connectivity rates at least 100 Mbit/s).

	Independent variable:	
	GRTH	
	Model (1)	Model (2)
	All sectors All regions	All sectors Non-urban regions
GRTH(*t*-1)	-0.0811	-0.1807
	(0.0828)	(0.1297)
GDPPC (*t*-1)	0.0119	0.0163**
	(0.0073)	(0.0062)
Broadband (100 *Mbit/s*)	0.0869	0.0232
	(0.1932)	(0.3048)
Broadband squared	-0.0601	-0.0175
	(0.1180)	(0.1865)
Population growth	-1.0311	-2.4196
	(0.8234)	(3.5006)
Gross fixed capital formation	0.0232	0.0157
	(0.0130)	(0.0145)
Government expenditure	0.0644	0.1479
	(0.1197)	(0.1126)
Observations	43	30
Sargan test p-value	0.0303	0.3413
AR(1) p-value	0.0061	0.0315
AR(2) p-value	0.7852	0.6320
Note:	*p<0.1; **p<0.05; ***p<0.01	

Thence, when we turn our attention to disaggregated variables with sufficient explanatory capabilities and an indisputable indicator of regional wellbeing, our seemingly reverse circular reasoning is fulfilled and we inevitably return to data on formal sector employment, similar to our earlier European analysis in which we were obliged to include these proxies due to a lack of the aforementioned variables. Table 9 presents these results for broadband coverage offering access to network speeds of at least 30 Mbit/s. When we focus solely on connectivity rates of at least 100 Mbit/s, all results are identical.

Table 9: The effects of fixed broadband coverage on economic growth in Belgium (connectivity rates offering at least 100 Mbit/s). Data on formal sector employment is included.

	Independent variable:	
	GRTH	
	Model (1)	Model (2)
	All sectors All regions	All sectors Non-urban regions
GRTH(*t*-1)	-0.1190	-0.1608
	(0.0804)	(0.1395)
GDPPC (*t*-1)	0.0413**	0.0570
	(0.0133)	(0.0584)
Broadband (30 *Mbit/s*)	0.1458	0.0043
	(0.3544)	(0.6986)
Broadband squared	-0.0904	-0.0047
	(0.2036)	(0.4000)
Population growth	-1.5924**	-2.6733
	(0.6134)	(3.2358)
Employment rate	-0.1207*	-0.1671
	(0.0526)	(0.2122)
Employment growth	0.6517***	0.6851
	(0.1494)	(0.4577)
Observations	43	30
Sargan test p-value	0.0870	0.3413
AR(1) p-value	0.0115	0.0315
AR(2) p-value	0.9893	0.6320
Note:	*p<0.1; **p<0.05; ***p<0.01	

The significance of our control variables now reappears when we consider all regions as a whole but disappears if we shift our focus solely to predominantly rural and intermediate areas. However, the broadband coefficients are not significant for Belgium, indicating that providing broadband infrastructure with connectivity rates of at least 30 Mbit/s did not contribute to recent economic growth. This result can possibly be explained by considering the fact that our descriptive analysis revealed near-saturation in urban Belgium since almost the start of our considered time horizon, combined with the insignificant results when we solely consider non-urban Belgium.

4.4. Conclusion

Regional analysis of the relationship between telecommunications infrastructure and economic growth confirms the earlier findings of a positive and significant impact at the country-level. After a certain threshold speed level is reached, further increasing broadband speed does not translate into additional economic growth for the agricultural sector specifically, but when we consider the European economy as a whole, we do find significant effects for higher connectivity rates. Especially in terms of connectivity rates offering at least 100 Mbit/s, this threshold level has long been attained in urban Europe as our results indicate a stronger rural impact on economic growth, while rural areas are still falling behind significantly in 100 Mbit/s broadband infrastructure compared to their urban counterparts. However, most private investments remain allocated to providing even faster connection rates in urban areas, despite the welfare gains being long overdue. At the sectorial level, the agricultural industry witnessed large gains from digitalisation between 2011 and 2018, aligning with the emergence of innovations in smart farming technologies and reassuring its importance in the future.

The benefits are not limited to densely populated urban areas, but in fact spread out across all regions. Additionally, we find evidence for diminishing returns to scale in broadband infrastructural investments, providing even more incentives to narrow down the urban-rural digital divide as a larger chunk of the returns to scale in rural regions are yet to be reaped.

When we conduct a country-specific analysis for Belgium, we do not find any significant impact of broadband infrastructure on economic growth, regardless the specific speed thresholds. Moreover, the use of some well-established control variables at the national level were not capable of adequately explaining regional differences in economic growth, stressing the need for future research investigating key determinants for quantitative regional assessments.

Further research should theoretically investigate the specific channels through which broadband provision affects economic growth. As access to high-speed virtual networks are a prerequisite to build and extend the digital economy on both the supply and consumption sides, its microeconomic determinants should be more closely examined and framed within endogenous growth theory. Moreover, the role of mobile telecommunications cannot be neglected, and warrants its own analysis.

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