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The European digital single market strategy: Local indicators of spatial association 2011–2016

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A B S T R A C T

This paper describes the space-time dynamics of the European digital divide. The frequencies of internet and E-commerce use are considered, along with a broad range of indicators associated with the European digital single market strategy. This paper aims to investigate the spatial structure underlying these aggregate outcome indicators. An exploratory spatial data analysis is conducted in a sample of 209 regions using Eurostat data. Strong evidence for both global and local spatial autocorrelation is found for the years 2011–2016. Consistently, a North-South polarization scheme is identified with little statistical significance in the centre of Europe. This contrasts with the high income cluster found in central Europe, while low values for digital indices and income are co-located more consistently in the South, but also in the North-East. Highlights from the specific results include: areas surrounding London as a dynamic high value cluster in E-commerce, Italy to conduct few cross-border purchases, France as a consistent adopter of E-governance, and broadband rates in general to closely reflect online activities.

1. Introduction

The European Commission declared their digital single market (DSM) strategy a top ten priority, committing €61,3 billion for the budgetary period from 2014 to 2020. The strategy is economically motivated and includes a broad range of initiatives build around breaking down the barriers to cross-border E-commerce, the facilitation of high speed broadband investments, and innovation in the ICT sector. The European Commission (2015) motivates the DSM by referring to a productivity advantage in ICT, of the United States over the EU, estimated to lead to 0.2% greater annual growth. This paper emphasizes the prerequisite factors of internet use in the general population, as well as E-commerce, where the frequencies of engaging in the activities are well documented.

The first contribution of this paper is the wide ranging nature of the Exploratory Spatial Data Analysis (ESDA) of the DSM. It is a rare example of such a study in digitalization, while the first reason it can be considered wide ranging is because it is simultaneously sub-national (209 NUTS[1] regions) and cross-European. Secondly, a broad range of digital indicators from Eurostat is applied, where after noting the progress towards designated policy goals, we can determine the detailed spatial structure underlying these aggregate outcomes. The quantifiable policy variables considered are: broadband connections, 'on-the-go' internet access, cross-border E-commerce, E-governance, and ICT patents. An ESDA is an empirical search for patterns, although statistical in this instance, essentially a descriptive method. The Local Indicators of Spatial Association (LISA) provide a structured view of the spatial heterogeneity present in the variable of interest. They can be used to provide visualizations of spatially consistent clusters of particularly high or low values. The ESDA of this paper was influenced by the approach of Ertur and Koch (2006) and their investigation of the

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[1] Nomenclature of Territorial Units for Statistics is a geocode for subnational data in the EU. NUTS2 (276 regions) is more detailed than NUTS1 (98 regions).

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changing nature of the North-South polarization scheme in income inequalities,[2] in light of the European Union's eastern expansion. The Chinese experience in the early stages of internet adoption, as documented by Liu and Zhang (2004), however, has shown that income and digitalization need not be closely co-located. This paper thus also sets out to answer the question if the spatial polarization underlying these two variable types is comparable in Europe.

The second related contribution to the literature is the description of the space-time dynamics of the digitalization process. This considerers the percentage point growth of the introduced variables between two time periods, known as a differential local Moran's I. Among several other methods, Billon, Ezcurra, and Lera-Lopez (2008) conduct a LISA for internet use based on a Eurobarometer survey for 76 regions, excluding Eastern Europe. They describe a pattern for 2003 with high value Northern and low value Southern clusters. Digitalization, however, is a highly dynamic process; as for instance the weekly users in the Italian region of Campania grew from 21% in 2006 to 56% in 2016.[3] Data coverage now allows for a more complete visual representation of Europe through five years, from 2011 to 2016.

This study finds evidence for both global and local spatial autocorrelation and a North-South polarization scheme, where Northern European regions are more digitally advanced than Southern and sometimes Eastern regions, with little statistical significance in central Europe. Despite rapid growth in most variables, the digital divide is highly persistent from 2011 to 2016, and is visible in the stages from broadband penetration, to internet use and E-commerce. Equally important for this paper are the specific spatial patterns displayed and their variations from the established pattern. In order to provide a sufficient level of detail, a summary of these finding is provided in the conclusion.

Due to the broad and descriptive nature of the analysis, the paper proceeds in the following way. Section 2 provides some background literature on the digital divide and an overview of the DSM and targeted policy variables. In a direct transition, Section 3 describes the data used and the additive indices for frequencies, along with the regional classification applied. Section 4 considers the LISA, spatial weights matrix, and transitions towards the results by considering Moran's bivariate scatterplot. Section 5 compares results on the user and commercial indices and lays out the overall trend. Section 6 considers dynamics in the commercial index and relates to regional economic conditions. Section 7 applies the established methods to a broad set of policy relevant variables, before section 8 discusses statistical significance. Finally, section 9 concludes.

2. Literature and policy

2.1. Digital divides

This work is set in the extensive and interdisciplinary literature concerned with the digital divide. To capture the complexity of unequal digitalization a wide range of composite indicators have been constructed as described by Sciadas (2004), while factor analysis has also proven popular (Cruz-Jesus, Oliveira, & Bacao, 2012; Ruiz-Rodriguez, Lucendo-Monedero, & Gonzales-Relano, 2018; Vicente & Lopez, 2011). This paper instead considers multiple individual indicators, while indexing the data based on how frequently an interaction takes place. To narrow the focus, emphasis is placed on studies that have a cross European, subnational, and sometimes spatial analysis approach. To contrast different geographic units used, other studies can be cross-national (Pick & Nishida, 2015), analyse regions within one nation (Grubesic, 2008), or consider more local spread (Grubesic, 2002). In line with much of the literature this work also considers the increasingly relevant inequalities in ICT use, extending the emphasis beyond ICT infrastructure availability[4] (van Dijk, 2012; Sciadas, 2004). Hüsing and Selhofer, 2002 distinguish between three observational dimensions: individual and household, region characteristics, and business or organization. This work considers the first two, while Cruz-Jesus et al. (2012) has shown that national e-businesses and internet access costs, for instance in Greece, can differ from infrastructure and adoption by the general population. The approach of this work is to describe the digital divide, while Vicente and Lopez (2011) highlight the distinction to those studies that try to explain it. The above authors also offer an in-depth review of explanatory variables, two of which require attention at this point. A starting point for the complex positive interactions with GDP can be the impact on the supply of telecommunications infrastructure. On the other hand, falling behind in ICT could amplify weaknesses of already economically struggling regions (Billon et al., 2008). The extent of the rural-urban divide as described by Salemink et al. (2017), can be connected to the spatial results of this paper, if it helps determine when neighbouring regions have similar ICT values.

Pierewan and Tampubolon (2014) present an observational visual display of internet use in 2010 (NUTS2), while also highlighting the upward trend in the variable. The European North-South divide in ICT (including low values in Eastern Europe) can be seen when mapping the data and is repeatedly described in the literature through different means, including rankings of factors or composite indicators (Vicente & Lopez, 2011).[5] Billon et al. (2008) both describe and explain in their spatial analysis discussed in the introduction, while also highlighting the unavailability of subnational time series data on internet use at the time. A recent example

[2] See e.g. Fredriksen (2012) for an overview of this well researched topic. Please also see Rey and Montouri (1999), as an application of local techniques to this toptic.

[3] Also in 2016, 86% of the population in Hovedstaden (Denmark) purchased online, while in Vest (Rumania) this was 8%.

[4] Czernich, Falck, Kretschmer, and Woessmann (2011) use a logistic function taking a characteristically 'S' shape, used in the epidemic approach, to explicitly model a technological diffusion process driven by infrastructure deployment. Diffusion in ICT can equally well correspond to phases for use by innovators, early adopters, early majority, late majority and laggards (as discussed in Pick & Sarkar, 2015).

[5] The European Digital Progress Report (2016) also spans descriptions of national data, such as basic and advanced digital skills being highest in the North of Europe in line with ICT use.

of a dynamic analysis is Szeles (2018), who found internet and e-commerce use to have similar explanatory factors in their data, which ranges from 2001 to 2016. This study, however, considers a narrower time frame (2011–2016), which allows to consider the developments in more policy relevant variables and achieve a level of detail that allows for a relatively complete visual representation of Europe. To justify the spatial dimension Billon et al. (2008) e.g. consider the diffusion of tacit knowledge, requiring face-to-face contact.[6] Billon et al. (2009) also found that spatial effects can be hindered by country borders in a regression for 2002, and provide another example of a LISA based on firms with their own website in 239 NUTS2 regions, finding high clusters in the centre of Europe and low clusters in the South and East. Going full circle to the concerns of defining and measuring the digital divide, this study takes a policy orientated approach as done with ESDAs on regional GDP (Ertur & Koch, 2006, Dall'erba, 2005) and embeds the selection of variables analysed in the data collection and policy framework of the European Commission. The literature review thus continues in the supplementary materials (S.1), with an overview of research relating to the expected benefits of the DSM and precursor initiatives.

2.2. Quantifying the digital single market strategy

Economic cooperation has been a cornerstone of the European project since its foundation, with the creation of the single market ensuring a free flow of people, capital, goods and services. However, in the digital arena, legal barriers between member countries and incomplete participation remain a concern. Concrete steps planed include reforming European legislation in the telecom sector, copyright law, audio-visual media, digital service provision and personal data protection. This top 10 policy priority of the European Commission more broadly aims at providing 1) unconstrained online access to goods and services, 2) the conditions for network infrastructure and content services investments and 3) the opportunity to realize the economic growth potential of innovation and competitiveness (European Commission, 2015). While the results section will first build a solid foundation by considering user and E-commerce rates, this section introduces the concepts behind the directly policy relevant variables.

The first pillar of the DSM stated above implies an increase in cross-border E-Commerce. Cardona and Martens (2014), control for consumer concerns by using testers to attempt online purchases, finding that in 48%[7] of attempted international purchases, sellers did not deliver to the required country, a circumstance known as geo-blocking. In contrast, a Eurobarometer survey considered real consumer experiences with cross-border E-commerce in 2014, and found 10% experience geo-blocking, 8% geo-filtering (varying sales conditions based on location), and 5% location based payment refusal, in a given year. Sellers may be constrained by manufacturer contracts or varying legality across borders. They may also simply face a cost disadvantage through increased overheads (e.g. delivery costs), or fragmentation in consumer laws or administrative procedures in value added tax[8] (European Commission, 2015).

The second pillar of the DSM is concerned foremost with the provision of broadband infrastructure across the European Union. It is argued that Europe requires reliable and affordable[9] high speed connections, to enable the development and use of advanced digital technologies[10]. Legislation and initiatives aim at increasing competition within,[11] and increasingly across member states, and realizing positive externalities. Already in 2010, the targets of universal access to 30Mbits and 50% access to 100Mbits by 2020 were set (European Commission, 2015). Europe's digital progress report (2016) states access of 68% to 30Mbits (uptake at 30%) and around 50% access of 100Mbits (uptake at 11%). Unfortunately, regional data availability does not include the speed of the broadband connections; however, we can additionally consider the share of the population using internet on-the-go. Rapid technological progress in mobile technologies, is expected to create an alternative pathway towards reaching 30Mbits speeds by 2020 (European Commission, 2015).

The third pillar of the DSM relates to competitiveness, which can be considered a multifaceted issue beyond the scope of this paper. The related second emphasis on innovation, however, can be measured with ICT patent applications based on their region of origin (see also Hargreaves, 2011).[12] Innovation and economic growth are considered closely related, while innovation in the digital sector often features immediate circulation and negligible marginal costs (European Commission, 2015). Please note that this section made no attempt to exhaustively describe the DSM and follows the logic set out by the European Commission. One further aspects of the DSM lends itself nicely to quantitative analysis, namely, the expected savings resulting through an increased use of E-governance processes. The interested reader can find a description of these in the supplementary materials S.1. The activities and contributions

[6] Such considerations can be a reason why agglomerations and distance matter. The authors consider in depth the research in new economic geography and connections with ICT. Hall and Kahn (2003) also stress the importance of network effects in technological diffusion, which are considered to be particularly strong in general purpose technologies such as the internet. Skill formation is described as a process of learning from your neighbours, while policy intervention could address constraining factors such as affordability or lacking skills.

[7] Cardona and Martens (2014) do caution that the artificial nature in mystery shopping processes could overstate the actual experience of regular consumers.

[8] Many of these factors may also be present in different forms in brick-and-mortar trade. See also Lamensch (2015) for details on European VAT taxation in a digital context.

[9] Among households without internet, 26% were deterred by service prices and 30% by equipment prices.

[10] Common examples for advanced digital technologies are the internet of things, cloud computing, or big data.

[11] For instance, incumbent firms tend to own physical wire connections to households from telephone networks, where local loop unbundling is a regulatory approach allowing other providers shared or full access.

[12] Related to the concept of patents are copyrights, where instant online access to such material is beneficial, for research or media content alike. The DSM includes a set of initiatives to overcome the significant obstacles for access, particularly across international borders. Most users of Youtube will have experienced the error message “this content is unavailable in your country: /”.

stemming from the diverse European funding institutions are outlined in the supplementary materials S.2.

3. Data

3.1. Variables

The variables used stem from the Eurostat regional statistics by NUTS classification, subsections on the digital economy & society (isoc-i user survey[13]), science & technology, and regional economic accounts. The time period used spans from 2011 to 2016, with the exceptions of on-the-go access data becoming available from, and patent data being available until, 2012. The ICT variables are measured as percentages of the regional population, except broadband penetration using the proportion of households connected and patent data being count data. The two main variable categories are those that relate to the time interval since the last private online purchase, and the time-interval since the last internet use more generally. Regional GDP is measured in per capita at current prices, considering purchasing power parity (PPP), as is commonly done for international cross-regional comparisons (Ertur & Koch, 2006). The policy analysis considers regional broadband penetration, on-the-go internet access, international E-commerce, E-governance (interactions and online forms), and ICT patents. Please see appendix item A.1 for a table of variables and definitions.

3.2. Additive indices for frequencies

In order to summarize the available frequencies of private commercial purchases into a single indicator, an index weighted by frequencies is constructed. If the entire population would conduct E-commerce on a quarterly basis, the index would take the value of 100. The weighting of population falling in less frequent categories decays by a factor of 0.5 per time interval.[14] One should note that the possibility of internet access is considered a given, which can be seen as a realistic assumption in the European context.

$$CI_{it} = [\varnothing_{1it} + (\varnothing_{2it} - \varnothing_{1it})0.5 + (\varnothing_{3it} - \varnothing_{2it})0.25] \quad (1)$$

Where CI_{it} is the constructed Commercial Index in NUTS region i in the year t. Private online buyers as a proportion of the population are considered in quarterly ($\varnothing_{1it}$), annual ($\varnothing_{2it}$) and less than annual ($\varnothing_{3it}$) timeframes. Besides defining the index specifically for E-commerce, we can define a second more general index for internet use:

$$UI_{it} = [(\gamma_{1it} + (\gamma_{2it} - \gamma_{1it})0.5 + (\gamma_{3it} - \gamma_{2it})0.25 + (\gamma_{4it} - \gamma_{3it})0.125] \quad (2)$$

Where, following the same procedure as described above, UI_{it} is the User Index in NUTS region i in the year t. The frequency of internet use can fall in the categories daily (γ_{1it}), weekly (γ_{2it}), quarterly (γ_{3it}) and annually (γ_{4it}). A problem in comparison arises between the two indices, since the starting intervals differ and the last category of the commercial index is open ended. However, the actual values of the commercial index were lower than the values of user index in all instances. This at least, is consistent with the notion that being an internet user is a necessary but not sufficient condition for being an online purchaser.

3.3. Nuts classifications

The finest consistent level of analysis possible are NUTS2 regions (164 in 2016), however, this number restricts the effectiveness of visually displaying the results for the whole of Europe. Where systematic gaps in the data exist, the next less precise level of regional data was used. Applying this procedure leads to a classification with the maximum number of 209 NUTS regions, of which 164 are NUTS2, 45 are NUTS1.[15] The classification was tailored to most effectively display the results for 2016. The 2011–2016 growth comparisons have lower sample sizes (n = 177), because of variabilities in the data available in 2011, and because data availability in general has increased since 2011. Please see supplementary materials S.4. for a comparison of the full set of NUTS2 regions and the applied 209 regions. The disadvantage of combining different NUTS levels lies in the lower comparability with methodologically similar studies.[16] Le Gallo and Ertur (2003), for instance, used a similar approach in their regional classification.

4. Method

4.1. Local indicators of spatial association

This paper uses local indicators of spatial association (LISA) to conduct an exploratory spatial data analysis (ESDA).[17] ESDA is

[13] This relies on 150,000 households and 200,000 individuals, where NUTS1 declarations are required and NUTS2 declarations are optional (Eurostat Metadata, 2017). Eurostat flags problematic data points; e.g. for a full (all NUTS levels) data extraction based on 2016 private annual purchases these made up 4.5%, nearly all due to brakes in the time series.

[14] In other words, the % of the population conducting e-commerce only on an annual basis is given half the weight, those that purchase less than annually, receive a quarter of the weight.

[15] N.B. The income data considers only NUTS2, while patent data stands out with 1186 observations.

[16] Including very small countries. Partial data on Turkey was excluded as the lower rates would have impacted the mean on which the LISA is based. Other Non-EU countries where data was available such as Norway, were included to avoid geographical gaps.

[17] Which could also be used to inform the specification of spatial econometric models in a subsequent separate step.

argued to be most applicable when the precise form of diffusion is not known theoretically (Messner et al., 1999). This paper structures the associations with neighbouring regions through a spatial weights matrix, defined by its 10 nearest neighbours. Generally, spatial heterogeneity and dependence can be difficult to distinguish, as the degree to which the current pattern emerged from structural changes or true contagion remains unclear (Anselin, 2010). The Moran's I is calculated as a test for spatial autocorrelation on the global level, against the alternative of a random distribution. The emphasis here is on identifying statistical significant autocorrelation in local areas, including those representing spatial non-stationarity. Simultaneously determining, whether this co-location is of particularly high or low values as compared to the mean, through the LISA (Anselin, 1995). Unlike Ertur and Koch (2006), this study does not consider the equally valid spatial statistics by Ord and Getis (1995), to maintain the focus on the wide range of variables relevant for the policy analysis. In effect, the LISA allows for the calculation of a pseudo-significance level and determining whether a spatial cluster of particularly high or low values exists. The formal notation on the autocorrelation tests and the spatial weights matrix of the next section can be found in the supplementary materials S.3.

4.2. Spatial weights matrix

The spatial weights matrix in European sub-national comparisons of regions, can be defined by the k-nearest neighbours, where the number of neighbours considered is 10, as described by Dall'erba (2005) or Ertur and Koch (2006):

$$w_{ij}^{*}(k) = 0 \; if \;\; i = j$$

$$w_{ij}^{*}(k) = 0 \; if \;\; d_{ij} > d_i(k)$$

$$w_{ij}^{*}(k) = 1 \quad if \;\; d_{ij} \leq d_i(k) \;\; and \;\; w_{ij}(k) = \frac{w_{ij}^{*}(k)}{\sum_j w_{ij}^{*}(k)} \tag{3}$$

Where $d_i(k)$ is the cut-off distance for a region i in all directions (greater circle), which ensures that exactly k neighbours are included, and is calculated between regional centroids (Ertur & Koch, 2006). Le Gallo and Ertur (2003) mention that a choice of $k = 10$ for an average European region roughly implies the inclusion of neighbours of second order contiguity. As this is difficult to determine exactly in this context, queen contiguity matrices are presented as an alternative in the discussion section. More generally, the choice of $k = 10$ nearest neighbours lessens the impact of coastal features, the edges of the study area and varying regional sizes, while simultaneously placing no emphasis on directly shared borders. While the applied regional classification allows for broad data coverage for 2016, the consideration of growth rates limits the data availability somewhat; where the k-nearest neighbour approach implies that unlike in contiguity definitions, the next closest alternative region is selected to compensate for the missing data.

4.3. Moran's bivariate scatterplot

The deviations of the variables from their mean values are considered, such that the value of I is equivalent to a regression coefficient of **W**y on y. This in turn can be visualized as a bivariate scatterplot. Outliers could further be considered in the sense of normalized residuals, whose presence could e.g. indicate problems in the spatial scaling (Anselin, 1996).

The graph of Fig. 1 is centred at the point where the four quadrants meet. Quadrants II and III, represent a positive spatial association. More precisely, quadrant II shows the regions with above mean commercial index scores being surrounded mostly by neighbours with above mean commercial index scores, while quadrant III shows this association for values below the mean. The observations appear to be spread relatively evenly across the spectrum, implying that neither high nor low associations dominate the identified spatial autocorrelation and providing no indication of problems in the weight matrix specification. Also, observations tend to fall within a reasonably close band to the line of best fit. With 0.815 (out of 1) the value of the Moran's I is high. Quadrants I and IV represent negative spatial association, but relatively few observations fall into these, and where they do, they tend to be close to the quadrant borders i.e. mean values. Quadrant IV denotes regions with above mean commercial index values surrounded by neighbours with below mean commercial index values (diamonds in the rough), while Quadrant I contains regions with below the mean commercial index values that are surrounded by neighbours with above the mean commercial index values. These rare instances are generally considered to be of limited interest for the results obtained, although they might point towards bottlenecks or best practice cases from a policy perspective. On the whole, the evidence suggests that the global indicator of spatial association is a good indicator for the spatial process at hand, with little indication for local non-stationarity in this instance (Anselin, 1996).

When considering Fig. 2, one can notice some minor differences. For one, the Moran's I value computed is slightly lower with 0.770. In quadrant III, there is a wider spread from the mean compared to Fig. 1. There appear to be several remaining co-located laggards in internet use, however, on the right side of the line of best fit. This implies varying user index values in universally low value neighbourhoods.

5. Results section I: a European digital divide

5.1. User index

This section provides an overview of the spatial patterns the considered European digital divide takes across the two indices weighted by frequency. In absolute terms the average regions user index increased from 63.2% in 2011 to 74.8% in 2016. In the same

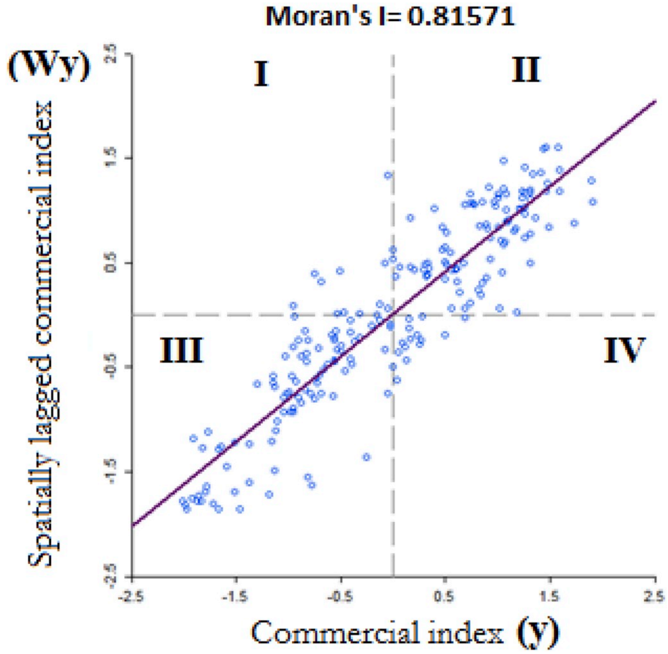


Fig. 1. 2016 commercial index (additive frequencies) Moran's scatterplot.

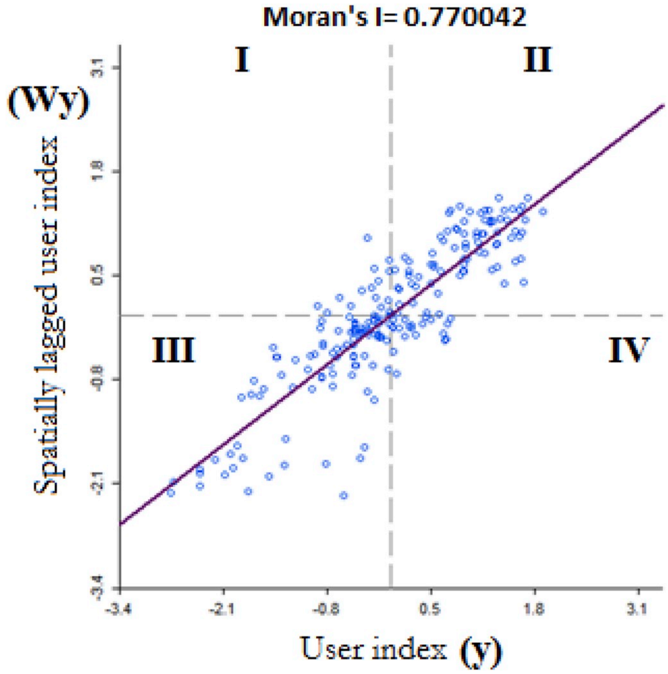


Fig. 2. 2016 user index (additive frequencies) Moran's scatterplot.

timespan daily users increased from 56.2% to 69.2%, at least weekly users from 67.9% to 77.3%, at least quarterly users from 71.5% to 79.9%, and at least annual users from 73.4% to 81.5%. The spatial patterns in the weighted combination of these variables are analysed below:

Fig. 3 indicates the regions where evidence for local spatial autocorrelation was found, where darker shades imply stronger statistical significance (from the 95% required to be a significant cluster, up to the 99,99% pseudo-significance level). The most convincing statistical evidence was found in Northern and Southern regions, including Scandinavia, the United Kingdom, Netherlands, Italy, Greece, Bulgaria and Rumania. In several other areas the statistical evidence was still above 95%, while no significant evidence was found in Europe's centre; in parts of countries such as Germany and France, but also northern Spain. In these areas the

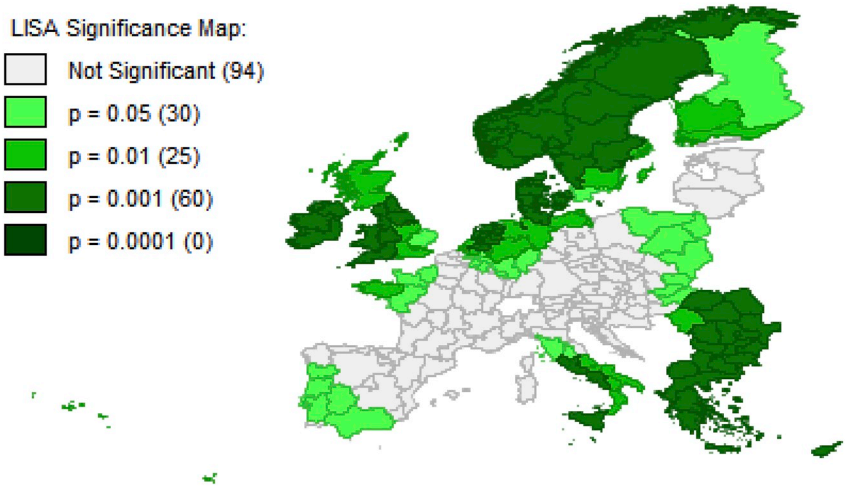


Fig. 3. 2016 user index (additive frequencies) LISA significance map (n = 209, 999 permutations, I = 0.770).

user rates tended to differ to a relatively large extent from one region to the next. Fig. 4 indicates significant and positive spatial autocorrelation for high (red) and low (blue) values. Red areas thus indicate a region with a high value surrounded by neighbours with mainly high values, while a blue region indicates the same association for low values. We generally see a reconfirmation of the notion that the North has higher rates than the South, while facing some imperfections in the North-South polarization. The mentioned polarization is upset by a low value cluster spanning the Eastern side of the continent, stretching from Greece through to Poland. Other low value clusters can be found in Southern Spain, Portugal, Italy and Greece. High adoption clusters, on the other hand, are found in a V-shape, in line with the continents geography, ranging from the UK to Belgium and inflecting to Scandinavia.

5.2. Commercial index

In absolute terms the average regions commercial index increased from 36.6% to 47.2% between 2011 and 2016, where the percentage point increase is of a similar magnitude to that of the user index, although from a lesser starting value. In the same timespan the amount of quarterly private online purchasers increased from 30.2% to 40.4%, the amount of at least annual purchasers from 40% to 50.6% and more than annual purchasers from 45.8% to 57.4%. The results for the combined and weighted index are presented below:

Compared to the earlier user index, Fig. 5 reveals remarkably similar locations and strengths of evidence for the regions that show statistically significant clustering. The cluster map of Fig. 6 confirms the North-South polarization of the previous section. Less clustering in the North of Eastern Europe weakens the case for an Eastern extension to the polarization scheme. The minor additions to the significant clustering in France are of the high kind and that in Spain of the low kind, consistent with the established patterns.

At the closing of this section a step is taken back to consider the population that has never used the internet. Even though this is incorporated into the user index, its consideration in the 2010 digital agenda warrants a separate mention. The numbers declined

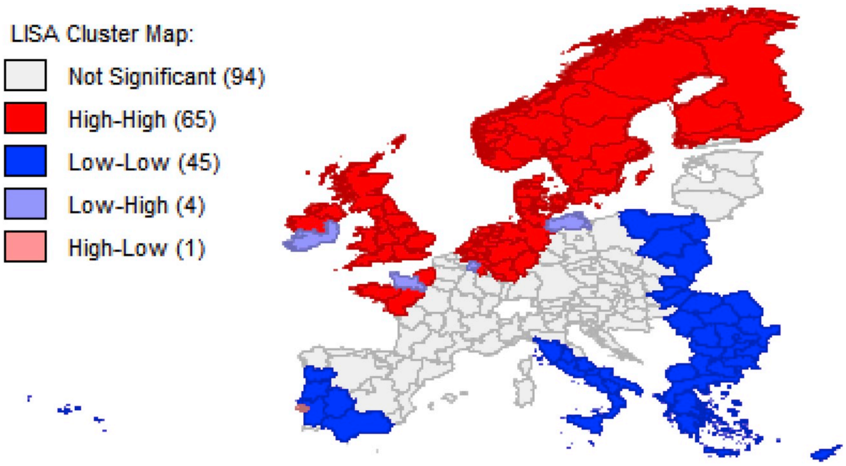


Fig. 4. 2016 user index (additive frequencies) LISA cluster map (n = 209, I = 0.770).

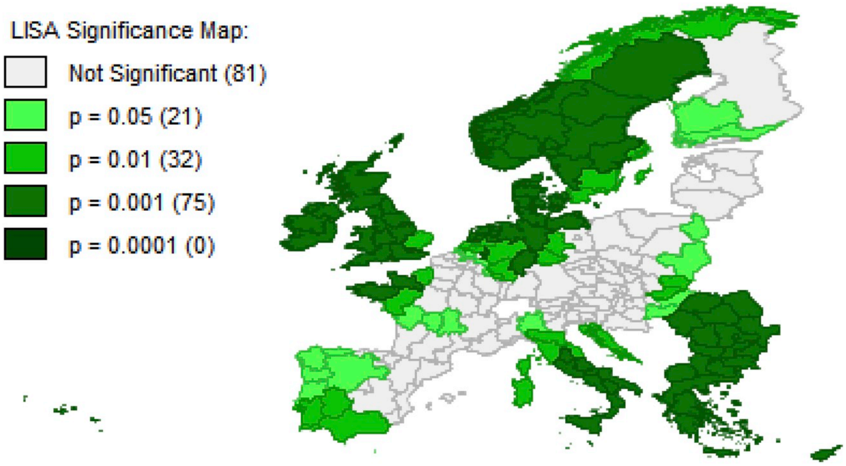


Fig. 5. 2016 commercial index (additive frequencies) LISA significance map (n = 209, 999 permutations, I = 0.816).

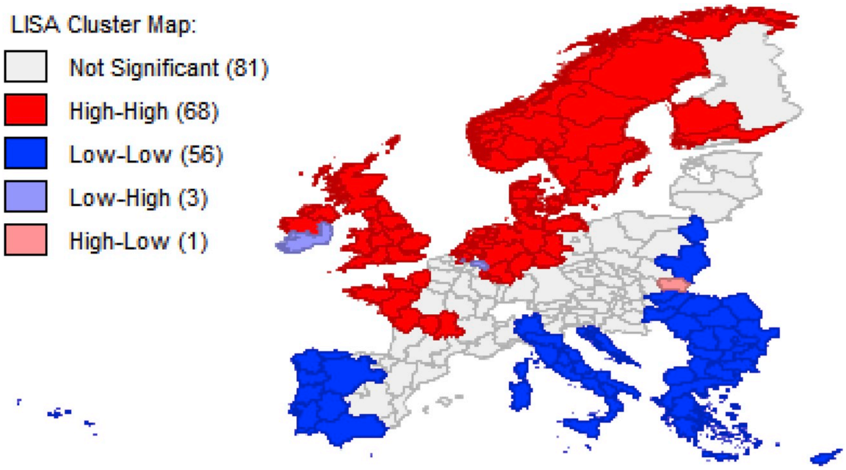


Fig. 6. 2016 commercial index (additive frequencies) LISA cluster map (n = 209, I = 0.816).

from 24.3% in 2011 to 16.3% in 2016, which are still none trivial amounts. While the 2016 analysis closely follows the confirmed patterns, the dynamic analysis indicates regions in the North-East where non-use persists (not displayed); it also appears as if user rates tend to plateau at different levels across countries. Section S.5 in the supplementary materials delves deeper and deconstructs both user and commercial indices into their individual components.

6. Results section II: commercial index dynamics and income disparities

6.1. Commercial index dynamics

This section introduces two new important aspects to the analysis. Firstly, the paper takes the step towards a dynamic analysis of changes. Thus we can go beyond a static view of 2016, and consider whether there is spatial clustering in the speed at which digitalization has advanced since 2011. Secondly, a bridge is built between the key commercial index to the well-researched theme of sub-national income inequalities across Europe. The growth results of digital variables have lower data coverage (177 regions), most notable is the absence of France. When discussing the dynamics of the commercial index in Fig. 7, references will also be made to the baseline results from Fig. 6.

Generally speaking, the Moran's I values were considerably smaller when conducting the analysis on growth rates in Fig. 7. Here, the low commercial growth clusters in Scandinavia and around Belgium might be due to saturation[18] while the low cluster in South-Eastern Europe displayed low absolute values along with low growth. London's surrounding areas show a consistent increase in commercial growth, despite already being a cluster of high values. Spain displays a cluster of high commercial growth, implying a

[18] Although absolute values in Belgium are only around 50–60% and between 60 and 80% in Norway and Sweden.

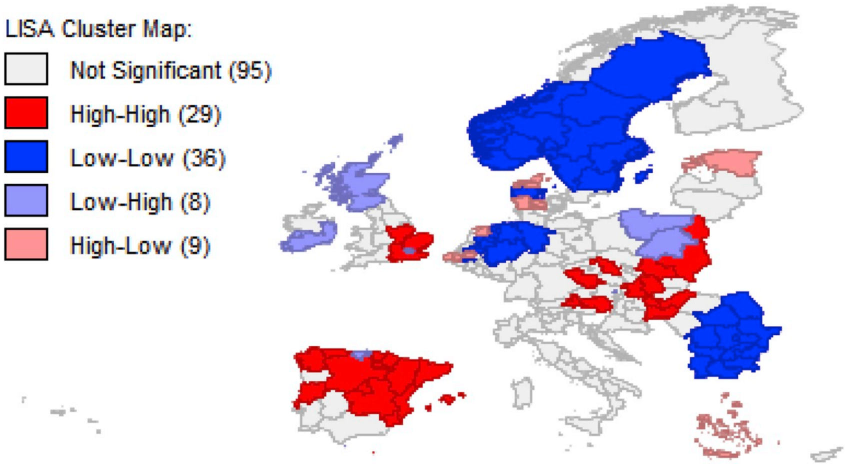


Fig. 7. 2011–2016 commercial index percentage point growth (n = 177, I = 0.216).

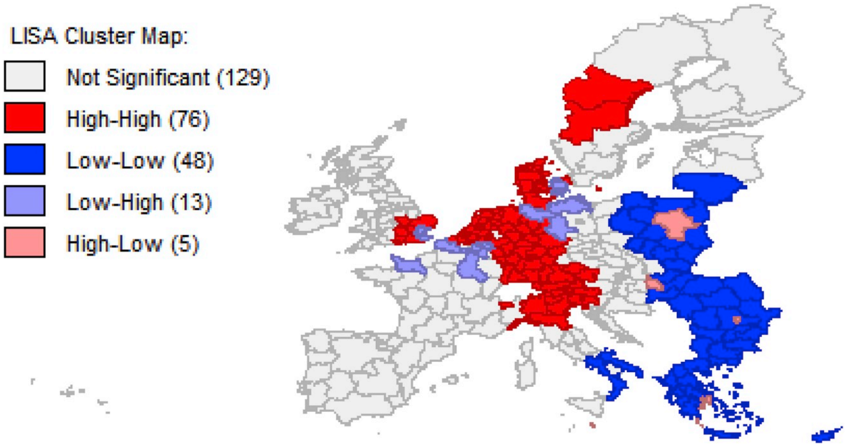


Fig. 8. 2015 log GDP in current prices per inhabitant at PPP (n = 271, I = 0.493).

catch-up process, since a low cluster is present in absolute values. A third somewhat scattered cluster is seen in the vicinity of Austria, suggesting many areas of high commercial growth with intermittent areas where this is not the case. As a final point, the commercial index only considers online purchases. Less emphasis is placed on online sales (appendix item A.3), as data is only available on an annual basis. This variable is also the only one seeing very little aggregate growth in the time period.

6.2. Regional income disparities

After analysing the user and commercial indices in depth, we can now draw comparisons to the clustering in regional GDP. This analysis uses 271 NUTS2 regions and year-on-year growth, in order to make use of the higher data availability of this variable and to be able to draw better comparisons to the literature, especially Ertur and Koch (2006).

Interestingly, the low value clusters in Fig. 8 can generally be found in the same countries as for the commercial index, while the high value clusters are not. The later are now predominantly in the centre of Europe, where the commercial index reveals no spatially consistent evidence for the congregation of high or low values. Although, Southern clusters are larger in the commercial index and clustering in the North-East of mainland Europe are smaller. The GDP significance maps (not displayed) indicated exceptionally high results (99.99% level) for the Eastern European cluster. Overall the results are similar to Ertur and Koch's (2006) LISA for the year 2000. The primary differences are that the central European high cluster extends slightly less to the West and Southern Italy is now in the low cluster.

For average GDP growth, Fig. 9 reveals more significant regions than Ertur and Koch (2006), with high spatial clustering (22.5% vs 12.8%) and low spatial clustering (19.2% vs. 13.6%). Not surprisingly, the average GDP growth results are less comparable at a later point in time and in a post financial and European debt crisis macroeconomic environment.

The Moran's I value for Fig. 9 is high compared to other growth analysis, although one should note that this is the only case were average growth rates are used unlike the usual differential local Moran's I. Besides Spain and Portugal's low clusters, Italy and Greece

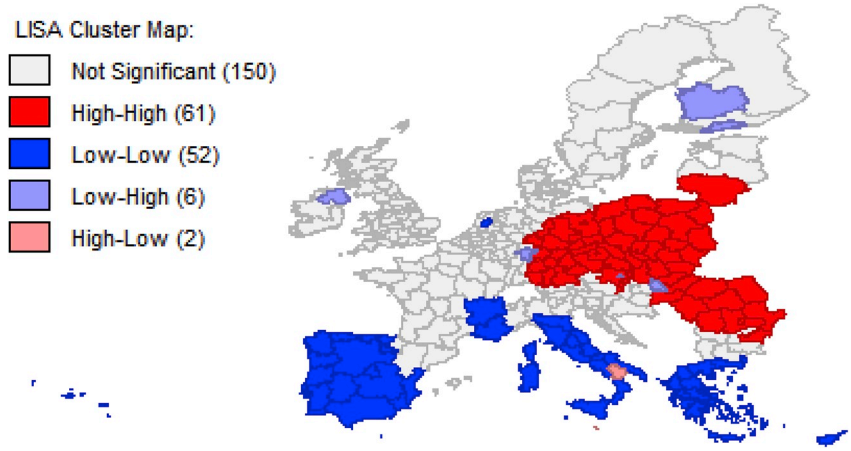


Fig. 9. 2010–2015 average of annual year-on-year GDP growth rates per inhabitant at PPP (n = 271, I = 0.482).

in addition showed remarkably strong statistical evidence for spatial autocorrelation.[19] The high growth rate cluster combines the economically catching up regions in Eastern Europe with the already high absolute GDP regions in the centre of Europe.

7. Results section III: policy benchmarks

In this section we take a step back from the user and commercial indices, which are relevant for building the base for a single digital market in general, and instead focus on specific policy targets set out by the European Commission. Where possible the policy goal will be stated and the recent progress achieved in absolute terms considered. The LISA categorizes according to mean diversions, implying it is not suitable as an additional measure of whether the goal was achieved. The LISA can, however, identify well performing or lagging spatial clusters. After applying the LISA to the 2016 values, the co-location in percentage point growth between 2011 and 2016 is analysed, e.g. to see whether clusters of lagging regions are catching up or falling further behind. The LISA thus operationalises the idea that the performance of neighbouring regions is not independent of one another, as for instance, the provision of broadband networks need not stop at sub-national boundaries.

7.1. Broadband penetration

One can begin by considering a three stage argument, where internet infrastructure enables internet use, which in turn enables diverse online activities.[20] The starting point of the policy analysis relates to infrastructure. However, one can simultaneously consider the element of connection speed, as concrete targets were set out by the European Commission. Broadband availability stands at 97%, while the targets set in 2010 refer to full coverage of 30mbits, as well as 50% coverage at 100mbits by 2020 (European Commission, 2015). Regional data availability does not include information on particular access speeds, while we can still consider the proportion of households that have broadband installed in a given region. In absolute terms, the in-sample average amount of households having broadband increased from 65.1% in 2011 to 80.4% in 2016, marking a comparably rapid increase.

The percentage of individuals with broadband on household level in Fig. 10 follows the same pattern of spatial clustering outlined in results section I. One deviation from the established clustering is noteworthy. In South-East France (Rhone-Alpes and Provence-Alpes-Cote d'Azur) a low cluster exists in broadband availability, which is not reflected in user or commercial indexes. As the regions names indicate, the alpine mountains may contribute to the result, although one should note that low values must be observed across the 10 nearest neighbours.

The 2011 data has lower coverage, most notably French data is not available with comparable regional detail. On the whole, however, the traditional pattern holds well in Fig. 11, but in reversed form. The typical high value clusters have apparently reached their saturation points and indicate little additional growth. At the same time several of the typical low cluster regions are seeing rapid increase in broadband penetration such as those surrounding Castilla-La Mancha in Spain, large parts of Italy and Eastern countries including Bulgaria and Romania. Notably absent, however, is the extension of the Eastern cluster into the North, for instance to Eastern Poland. This suggests that these regions are not, at least not uniformly, closing the gap in broadband penetration.

[19] 99.99% level (significance maps not displayed).

[20] Vicente and Lopez (2012) argue that 'readiness' in terms of internet infrastructure is required, before 'intensity' can measure the degree of usage, so that the 'impact' of an ICT technology can be discerned.

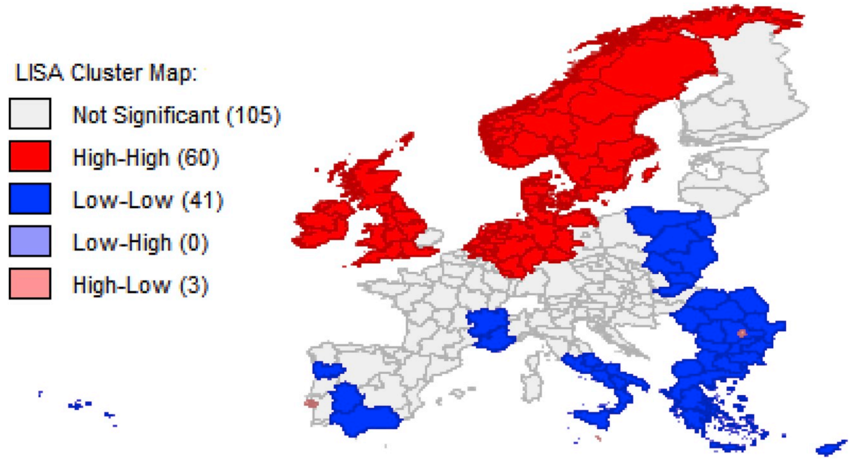


Fig. 10. 2016 proportion of households with broadband access (n = 209, I = 0.654).

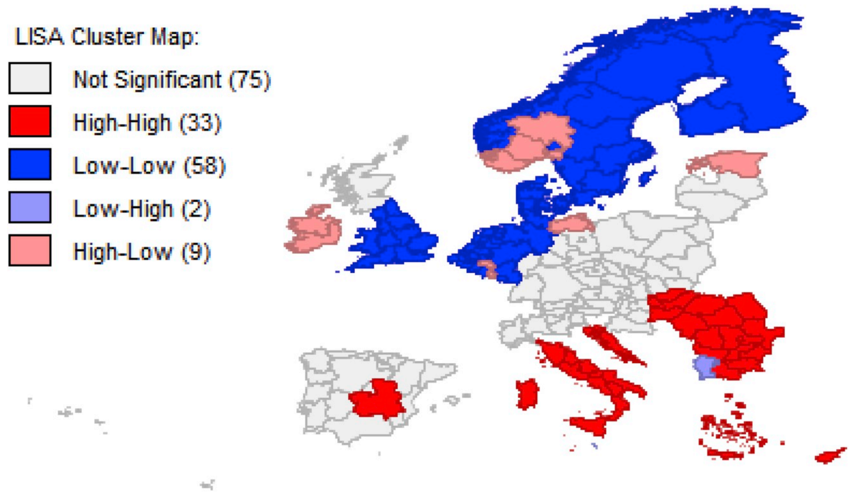


Fig. 11. 2011–2016 growth in broadband penetration on household level (n = 177, I = 0,575).

7.2. On-the-go access

Broadband connections on household's level cannot cover the entire spectrum of possible high speed ways to access the internet, particularly as wireless connections are increasingly becoming an alternative in remote regions or for individuals seeking alternative access modes. The variable ‘on-the-go’ measures the use of devices to access the internet, when neither at home or at work. Since measurement began on this variable in 2012, average rates have increased markedly from 35.4% to 59.5% in 2016.

The rates for on-the-go access in 2016 are consistent with the general trends of results section I. One deviation from the established trend in Fig. 12 is a high cluster in Eastern Spain. Connecting back to the previous section, we saw Spain having a low clusters of broadband penetration, which might together point towards the potential for reaching high access speeds via the mobile access mode in the near future. These kinds of considerations, however, require more in depth research. Also interesting, is the large size of low cluster surrounding Italy. Having now analysed separately the progressive steps of infrastructure, internet use and online commercial activity, we can note a highly persistent pattern through all the central aspects of this analysis.

7.3. International purchases

Progress in the European Commission's core policy goal of completing the single digital market is measurable by the amount of international online purchases. A central agenda item is the removal of the obstacles to such commercial interactions, as described in section 2.2. As initiatives to remove these barriers are continuing, we can outline the starting position from which one can measure future progress in light of the DSM. International purchases increased from an in-sample regional average of 11,96% in 2011 to 19.14% in 2016, just shy of the 20% digital agenda goal set for 2015 (Cardona & Martens, 2014). Please note that the underlying survey question refers to sellers in other EU countries and assumes respondents knowledge of this.

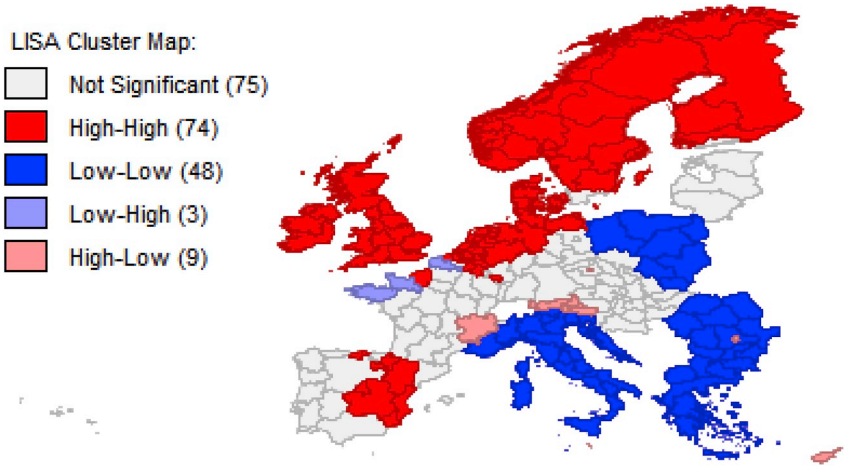


Fig. 12. 2016 proportion of population with on-the-go internet access (n = 209, Moran's I = 0.682).

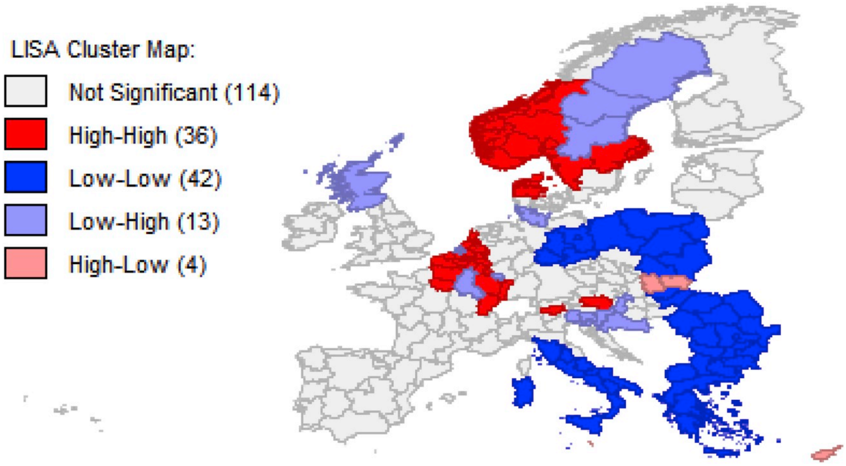


Fig. 13. 2016 proportion of population with international purchases (n = 209, I = 0.413).

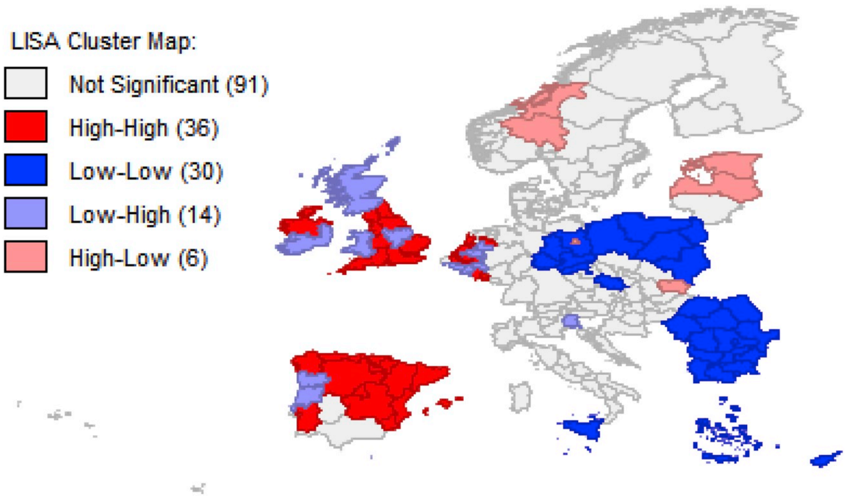


Fig. 14. Growth of population with international purchases 2011–2016 (n = 177, I = 0.344).

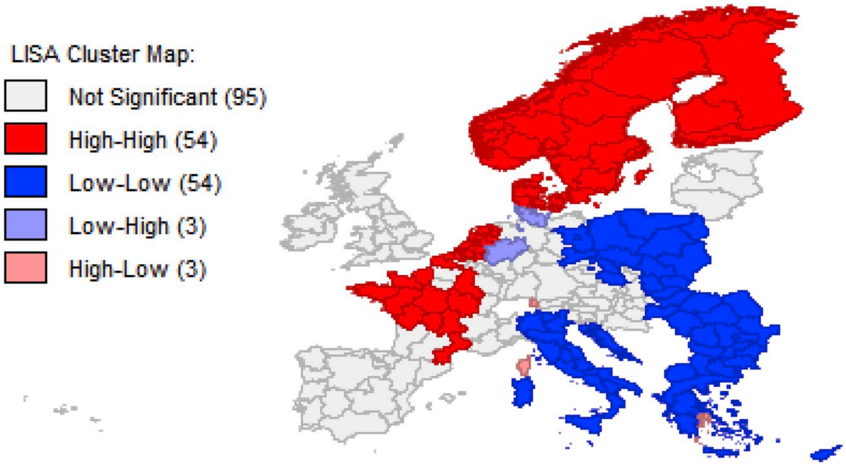


Fig. 15. 2016 indicator of E-governance use (online interactions and complete forms, n = 209, I = 0.713).

While there is statistical evidence for spatial autocorrelation, the Moran's I = 0.413 in Fig. 13 is the lowest value recorded in a cross-sectional variable. Clusters of frontrunners in international purchases can be found surrounding Belgium and the Netherlands, as well as in the South of Scandinavia. Furthermore, a single Austrian and North-Italian Region show up as high clusters, being encircled at some distance by clusters of particularly few international purchases, stretching from central Italy all the way to Belarus.

The Moran's I falls slightly when considering growth rates in Fig. 14, while still being reasonably far from zero. Consistently low growth clusters can be seen in many of the lagging regions of the previous analysis, with the notable exception of Italy, where the differences in regional growth rates imply that there is no significant clustering. On the whole, the consistent clusters of regions with low values found, are not catching up. The high clusters are even more interesting, as Scandinavia had high values in the earlier Fig. 13, but shows no consistent growth. The UK and Spain, which both did not see consistent clustering in high rates of international purchases, are experiencing spatially consistent increases. The cluster in the vicinity of Belgium is the only area where high values and high growth are clustered together.

7.4. E-governance

Another goal of the initiatives is the use of E-governance for simpler and more efficient interactions with authorities. An increased uptake of such services should lead to considerable cost saving potentials. The simple index applied consists of two equally weighted variables: 1) whether you have had online interactions with the authorities and 2) whether you have completed administrative forms online. The index increased from an average 32.7% in 2011 to 40.2% in 2016.

The results in Fig. 15 are rather similar to the established patterns of results section I, however, some regions are notably missing. No significant clustering arises in the United Kingdom, where E-governance is not prevalent across the entire country. Spain does seems to have some areas where E-governance is used to a large degree. Large parts of France show up as a new high cluster,

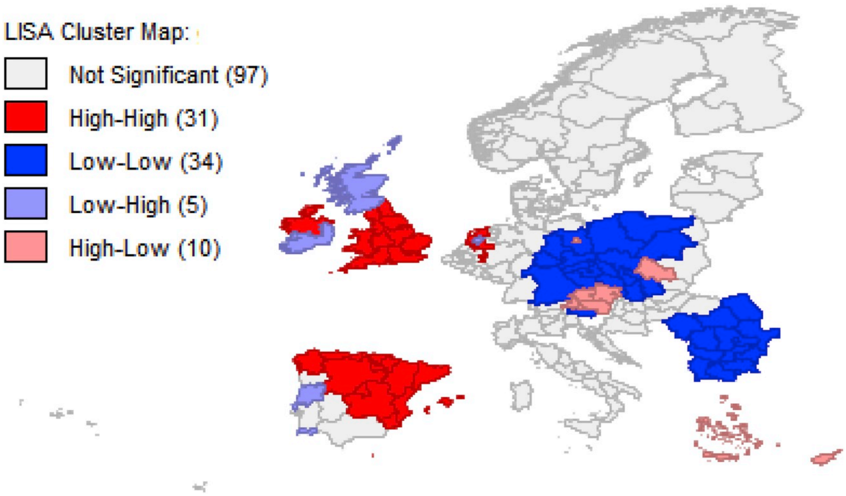


Fig. 16. 2011–2016 growth in E-governance indicator (n = 177, Moran's I = 0.320).

Table 1
2016 significance tests on commercial index results (n = 209) with 999 permutations and k = 10 neighbours, unless stated otherwise. Low (high) index decay has 0.75 (0.25) as its first weight, before halving this.

Significance/Commercial Index	Moran's I	Level: 95%	Level: 99%	Level: 99.9%	Level: 99,99%	Cluster: High-High	Cluster: Low-Low	North-South Polarization
2016 baseline	0.816	21	32	75	0	68	56	Yes
2011	0.795	35	30	69	0	65	63	Yes
Permutations 99	0.816	29	93	0	0	65	54	Yes
Permutations 50,000	0.816	22	27	28	58	66	56	Yes
Low index decay	0.822	29	24	72	0	68	55	Yes
High index decay	0.807	25	28	70	0	65	55	Yes
k = 5 neighbours	0.859	28	38	38	0	56	47	Yes
k = 15 neighbours	0.747	26	42	75	0	77	59	Yes
Queen contiguity order 1	0.854	33	23	24	0	46	33	Yes
Queen contiguity order 2	0.854	36	31	36	0	62	38	Yes

suggesting government interactions are consistently done online across much of the country, while high user index values were not prevalent. Northern Europe is also a very consistent adopter of E-governance. The clusters in Eastern Europe are also more sizeable compared to the baseline analysis, which along with Italy, form clusters where E-governance uptake is still in its early stages.

Fig. 16 displays high growth clusters in parts of Spain and the United Kingdom, while low clusters exist for instance around the Czech Republic and Bulgaria. The amount of significant clusters is quite low in this case. The existence of some negative growth rates should be noted. Finally, the preliminary analysis for the DSM pillar of innovation captured through patent data can be found in appendix item A.4, as it is not directly comparable, while yielding no significant spatial autocorrelation.

8. Discussion: statistical significance

This section should be understood just as much as a reflection on statistical significance in this context, than as a consistency consideration of the results. For tractability reasons, the cross-sectional results from the commercial index are used (see also the methods and first results section).

The North-South polarization holds consistently through the variations of Table 1, while the North-Eastern extension of the low cluster is sensitive to changes in the weight matrix specification. High permutation numbers increase statistical significance, with very little impact on numbers and directions of significant clusters. The weighting of the index plays a minor role. More neighbours in the original spatial weights matrix imply a lower Moran's I, but more of both high and low clusters. Exact identification of the (queen) contiguity order implies 12–15 regions without neighbours, accounting for the potential impacts of islands, and substantially more high clusters when considering second order contiguity. As these described impacts are very similar for the clusters found in the growth results, although the baseline amount of clusters is less, the table can be found in appendix item A.5. Despite the consistencies discussed, the exploratory results of this study and the comparisons between them should be treated with some caution.

9. Conclusion

Overall the paper has found strong evidence for local and global spatial autocorrelation. Global autocorrelation values were consistently higher for 2016, than for 2011–2016 growth. Such evidence was notably absent in the preliminary analysis for ICT patents, based on 1186 regions instead of the usual 209. The baseline result of this paper, the North-South polarization identified with the LISAs, is consistent with the 76 region analysis of Billon et al. (2008). However, low value clusters could also be found in the Northern parts of Eastern Europe, which showed sensitivity to the specification of the spatial weights matrix. The centre of Europe had few statistically significant results, implying that despite some regions having e.g. high values, their spatial neighbourhoods did not consistently display equally high values. For GDP in contrast, evidence for consistently high values in the centre of Europe was strong, as in Ertur and Koch (2006). The low value clusters for both GDP and digital indicators, on the other hand, are largely co-located. In absolute terms, the indicators have progressed rapidly from 2011 to 2016, with the notable exception of online sales. This might be due to a relative shift in the user population away from private selling. Overall, digital growth clusters were found both in leading and lagging regions, indicating mixed results on a spatially consistent closing of the digital divide.

Although the outlined pattern proved highly consistent, the specific results below focus on noteworthy departures and the varying dynamics in the variables. The spatial patterns in the E-commerce index and its growth rates suggest saturation in growth through low clusters around Belgium and Scandinavia, but not surrounding London. Spain on the other hand displays consistent catch-up, while parts of South-Eastern Europe continue to lag in unison. After covering the basis for the digital single market, the more concrete policy variables are now discussed. The findings include: Italy conducting few international online purchases and having no significant growth clusters, France as a consistent adopter of E-governance where data on growth rates are unavailable, and broadband connectivity to closely reflect the regular contours the digital divide draws throughout Europe in this paper.

There is a certain irony in analysing the spatial patterns in the use of the very technology often argued to substantially reduce the importance of geographic distances.[21] Variable interactions are also likely to play a part in the presented results. The natural progression implies that variable dependencies run from infrastructure to internet use and online activities. Broadband, however, was understood as a rough measure of speed and might also depend on end-user demand. Spatial interactions were understood as based on knowledge transfers and learning effects. These might help to understand why significant shares of the population are still not regular internet users and why E-commerce uptake trails considerably behind user rates. In addition, the closeness of the spatial structure underlying internet and E-commerce use, can be seen as complementary to the result of Szeles (2018) that similar explanatory factors appear to matter. Considering the regression analyses in the literature, future research could explain and not just describe this broad set of policy variables, including in depth considerations of GDP's role. One could also attempt to evaluate the policy effectiveness of the DSM strategy, which is complicated through its recent introduction and the lack of a counterfactual for comparison. Based on this we could better evaluate the benefits, potential detrimental side effects, as well as the prioritization choices in the implementation of this wide-ranging strategy.

Acknowledgments

I would like to thank the Vienna University of Economics and Business. I would also like to thank the Netidee foundation for its support during earlier research in this subject area. Finally, I would like to thank the two reviewers for their helpful comments.

Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.telpol.2018.10.003.

Appendix

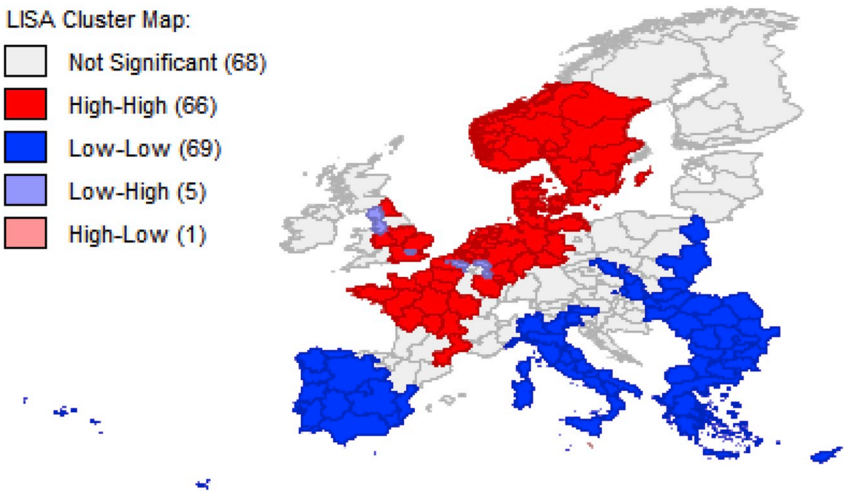
A.1: Table of variables (Eurostat codes, definitions and units of measurement)

Abbreviation	Code reg_isoc	Definition	Unit
Daily Use	I_IDAY	Frequency of internet access: Daily	Percentage of individuals in NUTS region
Weekly Use	I_IUSE	Frequency of internet access: Once a week (including every day)	Percentage of individuals in NUTS region
Quarterly Use	I_IU3	Last internet use: in last 3 months	Percentage of individuals in NUTS region
Annual Use	I_ILT12	Last internet use: in the last 12 months	Percentage of individuals in NUTS region
3 Months Buys	I_BUY3	Ordering goods or services over the internet for private use. Last online purchase: in the last 3 Months	Percentage of individuals in NUTS region
3–12 Months Buys	I_B3_12	Ordering goods or services over the internet for private use. Last online purchase: between 3 and 12 Months ago	Percentage of individuals in NUTS region
12 + Months Buys	I_BUMT12	Ordering goods or services over the internet for private use. Last online purchase: more than a year ago	Percentage of individuals in NUTS region
Annual Sales	I_IUSELL	Internet use: selling goods and services	Percentage of individuals in NUTS region
International Buys	I_BFEU	Individuals who ordered goods or services over the internet from sellers from other EU countries in the last 12 months	Percentage of individuals in NUTS region
Broadband Penetration	H_BROAD	Household internet connection type: broadband	Percentage of Households in NUTS region
On-the-Go Use	I_IUMD	Individuals used a portable computer or handheld device to access the internet away from home or work	Percentage of individuals in NUTS region
E-governance: Forms	I_IGOV12RT	Internet use: submitting completed forms within the last 12 months	Percentage of individuals in NUTS region
E-governance: Interactions	I_IUGOV12	Internet use: interactions with public authorities within the last 12 months	Percentage of individuals in NUTS region
ICT Patents	PAT_EPT_R ICT	ICT patent applications to the EPO by priority year. ICT-total.	Number of patent applications in NUTS3
GDP	PPS_HAB	Gross domestic product (GDP) in purchasing power standards (PPS) per inhabitant at current market prices	NUTS2 region

[21] Lendel, Olarreaga, Schorpp, and Vezina (2012), for instance, argue that distance effects decline by 65% on eBay compared to similar brick and mortar purchases, due to lower search costs.

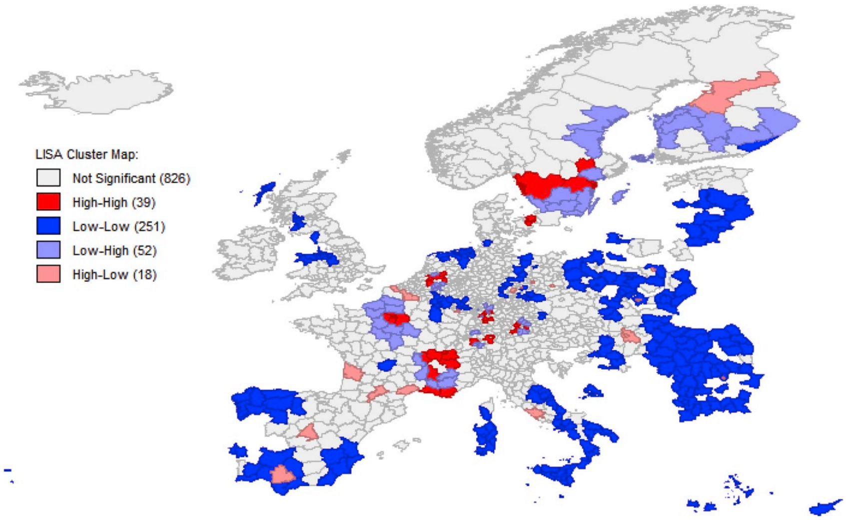
A.2: Moran's I for 2016 variables and 2011–2016 growth

Variable:	2016 Moran's I	2011–2016 Moran's I
User Index (UI)	0.770	NA
Commercial Index (CI)	0.816	0.216
GDP	0.493	0.482
E-commerce sales	0.730	NA
Broadband penetration	0.654	0.575
On-the-go access	0.682	NA
International purchases	0.413	0.334
E-governance	0.713	0.320
ICT Patents	0.074	NA



A.3: 2016 proportion of population with online sales (n = 209, Moran's I = 0.730).

The proportion of the population engaging in online sales annually increased only slightly from 14,2% in 2011 to 16% in 2016. This might be due to a relative shift from private to commercial selling. In absolute terms there were plenty of instances, where this rate dropped over the time period considered. The results are generally in line with the contours of the digital divide that have been outlined in results section I. However, the high clusters are comparably sizeable in continental Europe, as opposed to the UK and Northern Europe. The low clusters in Spain and Italy span most of the countries, while the North-Eastern European cluster is split into two separate entities.



A.4: 2012 patents in ICT. LISA cluster map (n = 1186, I = 0.074).

This analysis is considered preliminary e.g. due to the simplistic treatment of count data. The number of patents in ICT is available at the highly detailed NUTS3 level, allowing for 1186 regional observations. Due to this and data availability starting in 2012, where 12,626 patents were registered, comparability issues arise. Not least because patents can also be attributed to a region in part, only 376 of the regions had no patents granted.

This is the only instance where the Moran's I is not significantly different from zero, implying the distribution is statistically undistinguishable from a random allocation. However, local patterns are observed under this caveat. Only 39 regions are significant high spatial clusters (such as Ile-de-France including Paris), implying an imbalance towards the 251 low clusters identified, which have absolute values close to zero. While the negative values do congregate in the typical digitally lagging areas such as Spain, Italy and Eastern Europe, clusters are also present in central and northern Europe. The more fragmented nature of the clustering might be due to the absence of discernible global spatial autocorrelation and the level of detail in the data.

A.5: Significance tests on commercial index growth (2011–2016, n = 177) with 999 permutations and k = 10 neighbours, unless stated otherwise.

Significance/Commercial Index	Moran's I	Level: 95%	Level: 99%	Level: 99.9%	Level: 99,99%	Cluster: High-High	Cluster: Low-Low	6 Base Clusters
Base 2011-2016	0.216	50	28	4	0	27	35	Yes
Permutations 99	0.216	45	32	0	0	25	36	Yes
Permutations 50,000	0.216	50	25	5	1	26	36	Yes
k = 5 neighbours	0.257	34	8	3	0	15	24	Yes
k = 15 neighbours	0.175	61	26	4	0	33	35	Yes
Queen contiguity order 1	0.335	28	9	4	0	18	19	Mostly
Queen contiguity order 2	0.291	47	17	6	0	23	36	Mostly

N.b base clusters are Spain, North-Eastern Europe and London (high), and South-East Europe, Benelux, Scandinavia (low). Queen contiguity implies 12–16 neighbour less regions. Mostly means split clusters and no London cluster in one instance.

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