PÉCSI TUDOMÁNYEGYETEM
UNIVERSITY OF PÉCS

Dissertation Summary

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Pecs, 2024

Digitalization of Entrepreneurial Ecosystems and Smart Specialization: The Importance of Place Specific Factors

(Dissertation Summary)

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Pecs, 2024

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ABSTRACT

This dissertation looks into the complex interactions between the digitalization of entrepreneurial ecosystems, the concept of smart specialization, and the role of place-specific factors in the context of Europe. It is conducted an extensive examination of the adoption of digital web technologies across European regions to understand how the local environment serves as a connecting link between entrepreneurial ecosystems and smart specialization initiatives. By employing a mixed research methodology that integrates quantitative data analysis with in-depth case studies on selected web technologies, this study examines how geographical location, path dependence and the embrace of digital web technologies impact regional growth and labor productivity.

At the core of the study are three main questions aimed at discovering the connective role of local environment, the interconnections between geographical location and the adoption of digital technologies, and the association between digital complexity and regional economic performance within the European Union. The empirical approach includes spatial analysis, econometric models, and comparative case studies for specific web technologies, relying on a comprehensive self developed dataset regarding the use of digital technologies in several European regions.

The research finds that place-specific factors play an important role in the adoption of digital web technologies, which, in turn, significantly affect regional innovation ecosystems and industry specialization. The result highlights the paradoxical negative link between digital complexity and regional productivity, as well as between the density of related technologies and their adoption rates in European Regions, emphasizing the need for integrated policy measures that foster digital innovation and the development of digital local infrastructure. Also the importance of Core-Periphery dichotomy is discussed.

By offering concrete empirical evidence on the influence of geographical factors on the digital technology adoption of regional economies, this dissertation enriches the discourse on regional development, innovation policy, entrepreneurship and digital transformation. It advances the understanding of digitalization's impact on regional economic growth, how digital web technologies are adopted and provides valuable guidance for policymakers dedicated to strengthening regional innovation capabilities and competitiveness through tailored, place-based strategies.

1 INTRODUCTION

1.1 Introduction

While starting a new chapter of digital transformation era, the role of digitalization, capacity to adopt new technologies and entrepreneurship for regional economies becomes more and more essential in steering economic futures. The dissertation titled "Digitalization of Entrepreneurial Ecosystems and Smart Specialization: The Importance of Place-Specific Factors" looks into the complex interplay between digital technologies and the regional intricacies of entrepreneurial ecosystems. While the significance of digitalization has been recognized, the details of how companies are adopting new digital web technologies remain unclear. Moreover, this shift towards a digital web environment has been to a certain extent overlooked by regional innovation policies, often treated as an black box area, despite its essential role in directing innovation. This study selects the European Union's context to discover the effects of digitalization on smart specialization strategies (S3), but also how S3 influences the technology adoption, emphasizing the criticality of place-based factors.

The study's need has it's roots from the recent digital economy's advance of both it's theory and application, where the undertaking and integration of internet-based technologies are increasingly more and more necessary for regional productivity and economic output. Despite acknowledging the important role of digital web technologies in driving innovation and economic advance, a considerable knowledge gap persists regarding their adoption and absorption within diverse regional and industry specific settings. This dissertation aims to shrink this gap through a comprehensive analysis that enlightens the complex and context-dependent interactions between digital complexity, productivity, and digital web technology adoption across European NUTS2 regions.

Positioning itself between the discussions on digital change, innovation policies, and regional growth this research critically reviews theories on entrepreneurial ecosystems, smart specialization, and the impact of geographic, spatial and contextual factors. Including evidence from foundational theories but also recent studies, the dissertation advocates for a specific approach to understanding digitalization's interaction with regional innovation capabilities and regional economic strategies.

The reason for adopting this investigation is drawn from identified literature gaps, lack of digital technologies adoption studies and pivotal observations about importance of digitization, presenting a compelling case for an in-depth examination of digital technologies' role in regional economic development, especially regarding place-specific elements. The study's justification is mainly driven by five main motives, collectively emphasizing the research's necessity.

First, it is the digitalization's dynamic nature and observed regional disparities, that highlight the uneven digital transformation benefits distribution. Despite a general consensus on digital technologies as key economic growth pilots, understanding their varied impacts across Europe's diverse regions remains lacking. This research seeks to demystify the complex relationships between digital complexity, web technology adoption, and regional productivity under the umbrellas of the frameworks of smart specialization and entrepreneurial ecosystems, where digitalization is often viewed in as a separated matter.

Second, existing literature highlights the important role of geographical proximity, cognitive proximity and interconnected research and entrepreneurial networks in fostering innovation and technological diversification. This ecosystem based view, characterized by relatedness and a mesh of existing and emerging technologies, suggests a departure from conventional views on digital complexity and technology adoption, offering the opportunity for a more profound empirical investigation.

Third motive is the role of contextual and spatial dynamics in digital web technology adoption and digital complexity, while recognized for physical technologies, it demands further empirical exploration in the case of digital technologies. Although spatial factors and agglomeration effects are acknowledged for their innovation potential, the specific dynamics and spillover effects across different European regions are not completely understood. This study aims to fill this gap by closely examining how place-specific factors influence digital technology adoption and regional economic performance.

Fourth, integrating digitalization into smart specialization strategies offers a rich update for existing frameworks for research, but also novel empirical observations. While strategic regional factors and capabilities endowment is believed to significantly boost innovation and economic growth, empirical evidence on digital technologies' impact on smart specialization strategies, especially from a place-based perspective, is not present.But also their effects are underestimated. This research explores the interaction between digital complexity, adoption of related web technologies, and smart specialization strategies addresses the existent gap, and promising valuable policy insights.

The fifth reason is that the fragmented literature on the adoption of digital technologies, entrepreneurial ecosystems, and regional economic growth requires a holistic integrative approach. The study responds to previous theoretical calls for an integrated framework that captures the effects of firm functions digitalization on regional economies. Moreover it aims to advance early scholarly discussions and provide practical advice for policymakers and industry pioneer stakeholders about digital technology adoption.

The research was started to bring empirical evidence regarding the the challenges of firm digitization but also what digital economy presents to regional development comprehensively. By carefully analyzing the involved dynamics of regional economies, the study not only enriches academic debates but also guides the development of informed policies that focus on digital technologies implementation for innovation and economic growth in various regional environments.

1.2 Problem Statement

The core problem this dissertation examines arises from the challenges regarding the process of digitalization of entrepreneurial ecosystems, the planning and implementation of smart specialization strategies, and the crucial role of spatial and geographical considerations in these strategies. These challenges are layered, involving the difficulties of embedding digital technologies into regional development agendas, deciphering the patterns of technology adoption across diverse geographic settings, and unraveling the complex relationship between digital sophistication and regional economic performance.

There's a gap in research and policies when it comes to understanding how digital web technologies and their uptake are shaped by, and in turn shape, the local environment and geographical positions. We're missing detailed methods when examining digital relatedness and its impact on the regional economic output that connect digital growth, entrepreneurial ecosystems, and the spatial and geographical aspects of different places.

The dissertation also highlights that strategies for digital innovation don't make enough use of the unique aspects of place specific factors. Although we know beneficial advantages of localized production and agglomeration economies, there's a lack of specific policies that use these factors to enhance the adoption of digital technologies and spur regional economic advancement.

The importance of this study is driven by the changing dynamics of digital economies, where the integration of web technologies, the degree of their complexity, and the density of relatedness are increasingly essential adoption of new technologies that later are transformed into regional competitiveness and economic health. Still, the way how these digital dimensions interact with spatial factors and contribute to the digital smart specialization of regions remains inadequately explored.

This dissertation tries to connect and solve these gaps into a holistic framework by conducting an comprehensive analysis of how the local environment is used as a connective link between digitalization and regional development strategies. Through a detailed examination of the linkages between physical location, digital technology adoption, digital complexity, and regional economic vitality, the research seeks to uncover the spatial dynamics essential to successful digital transformation strategies. By acknowledging the importance of geographic context in driving the digitalization trajectories of entrepreneurial ecosystems and smart specialization, this dissertation argues that a deep understanding of these dynamics can lead to more effective digitalization routes of entrepreneurial ecosystems and smart specialisation.

Therefore, the study is positioned as a solution by examining empirical data and theoretical insights that can drive the formulation of place-specific digital innovation strategies. It states that policies should not only address the digital aspects of entrepreneurship and innovation, but also be customized to the unique spatial and geographic characteristics of each region. In this line Smart specialization efforts could be enhanced by adopting this strategy, and including digitalization resulting in a more dynamic, economically robust, and digitally progressive regional economy.

1.3 Research Aims and Objectives

The research aims to examine the relationships between the digitalization of entrepreneurial ecosystems, smart specialization, and the importance of place-specific factors within the European context. Moreover the study aims to explore how local environment acts as a connecting element between digital technology adoption, entrepreneurial ecosystems and smart specialization strategies, and investigates the extent to which physical location and web technology adoption influence regional productivity, innovation capacities and growth. Using mixed-methods approach such as spatial models, specific cases about web technologies the research seeks to understand the impact of digital complexity, relatedness density and technology adoption on regional economic development and provides insights for policymakers to enhance innovation capacity and competitiveness of regions through tailored, place-based strategies.

1.4 Research Questions

- Research Question 1: To what extent does local context serve as a linking factor between entrepreneurial ecosystems and smart specialization frameworks?
- Research Question 2: What is the relationship between physical location and digital web technology adoption, does the place still matter?
- Research Question 3: What is the relationship between digital complexity, relatedness, technology adoption, and EU regional productivity?

1.5 Research Model

The dissertation framework, enriched the understanding of digitalization and the possible regional framework, it shows a compelling story that demonstrates the transformative impact of digital technologies on the intricate relationship between smart specialization strategies and the entrepreneurial ecosystem. This unified view highlights the necessity of nurturing technological progress and web technology adoption within a context-rich setting, spotlighting the critical roles played by relatedness density and digital complexity in driving regional innovation and economic performance.

Digitalization is seen as a primary catalyst for growth, aided by relatedness density, which enhances the spread and uptake of novel technologies through cognitive and geographical proximity, technological interconnectivity, and digital complexity. Which later elevate organizational and regional competitiveness by advancing internet infrastructure and digital skills proficiency. The exploration into digitalization augments the initial conceptual framework, that makes the shift from physical to digital environment and the incorporation of advanced digital web technologies as essential for the fulfillment of smart specialization strategies and the success of entrepreneurial ecosystems.

This framework, in conjunction with the understanding gained from digitalization, emphasizes the importance of identifying and fostering competitive advantages and areas of technological expertise. The idea is to encourage regions to utilize their unique resources and abilities by investing in digital technologies that are relevant to their strengths, following the guidance of the European Union's Smart Specialization Strategy. This approach promotes the development of specialized domains of activity and technological proficiency to enhance economic cohesion and competitive advantage.

By incorporating the concept of the entrepreneurial ecosystem into this narrative, I highlight the beneficial relationship that can be exploited by and between various stakeholders, including enterprises, governments, educational institutions, and financiers, in creating an atmosphere that promotes innovation and entrepreneurship. The statement underscores the significance of context, encompassing spatial dynamics and cluster effects, in amplifying the economic advantages that arise from the adoption of technology.

This holistic model envisages a vibrant, recursive process of technological evolution and adoption, highlighted through digitalization insights. It illustrates how digital technologies catalyze innovation, enhance competitive standing, and stimulate economic expansion, championing strategic approaches to digitalization efforts. The model points out that contextual elements and policy measures play crucial roles in guiding economic progress toward enhanced productivity, growth, and innovation. It calls for a sophisticated policy design and execution approach, finely tuned to regional strengths and the broader context of global innovation networks, thereby acknowledging the intricate economic fabric where technology, knowledge, and situational factors intertwine.

This holistic model envisions a dynamic and iterative process of technical advancement and integration, emphasized by insights gained from digitalization. The framework model also demonstrates how digital technologies can accelerate innovation, improve competitive position, and boost economic growth by advocating for strategic approaches to digitalization initiatives such as related technologies. Moreover the framework shows that place specific factors and regional policy interventions are crucial in directing economic advancement towards increased productivity, growth, and innovation. Therefore, digitalization process calls for a sophisticated policy design and execution approach, which is carefully tailored to the specific regional capabilities and infrastructure but also takes into account the broader context of global innovation networks. In this framework it is recognized the complex economic environment where technology, knowledge, and contextual factors are interconnected.

This can be observed in the following framework:

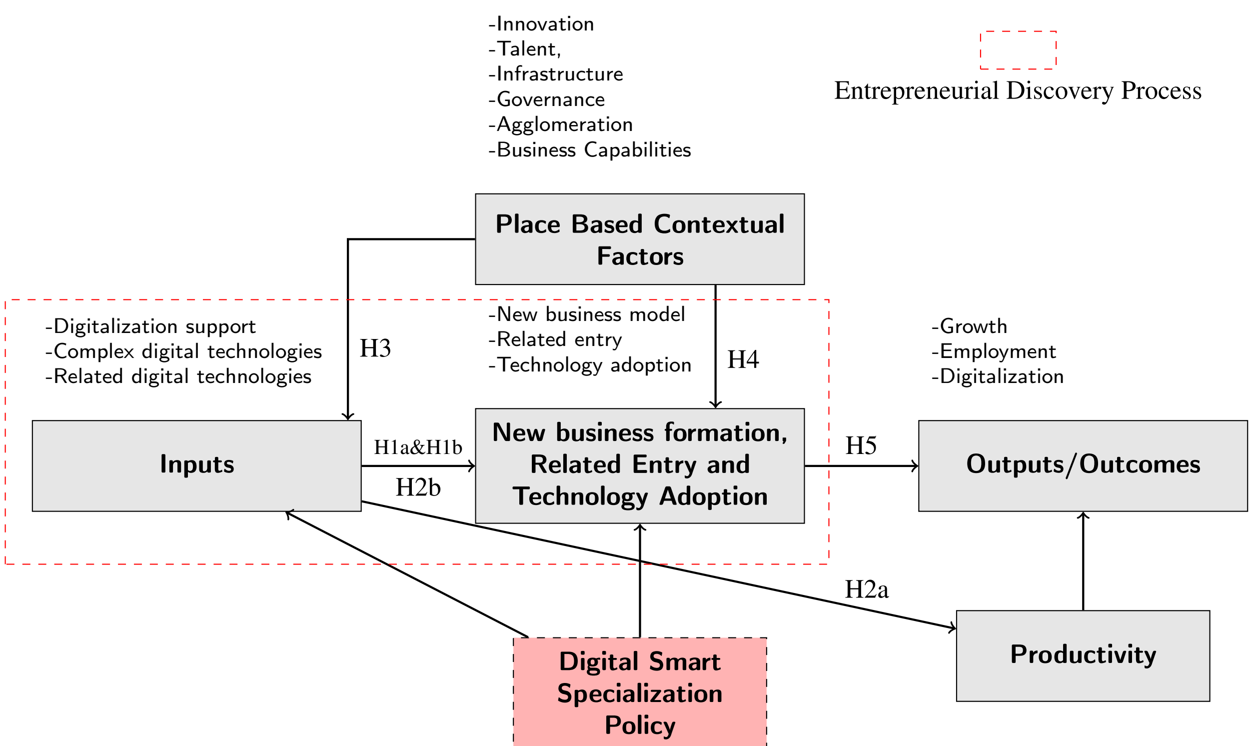

Figure 1: Conceptual framework of an Ecosystem-based Smart Specialization Policy and Hypothesis Development

1.6 Research Hypotheses

The thesis' hypothesis illuminate the complex interplay between relatedness density, digital complexity, technology adoption, and their collective impact on economic growth and regional development across European regions. These hypotheses are:

1. *Hypothesis H1a:* There is a positive relationship between relatedness density and related entry. In the case of web technologies high relatedness density, indicates a closer knowledge relationship between existing and new technologies. Relatedness density is expected to enhance the likelihood of related entry, where firms in regions enter new digital technological domains that are closely related to their previous capabilities

2. *Hypothesis H1b:* There is a positive relationship between relatedness density and technology adoption. High relatedness density, indicating a closer relationship between previous and new technologies, is expected to facilitate technology adoption.

3. *Hypothesis H2a:* Digital complexity positively influences labor productivity. Regions with higher digital complexity are hypothesized to exhibit higher productivity levels. When firms are digitized and have complex web technologies they are expected to be more productive, therefore influencing the overall regional productivity.

4. *Hypothesis H2b:* There is a positive relationship between digital complexity and technology adoption. Higher levels of digital complexity within a region are expected to lead to greater technology adoption rates. Here it is expected a spillover effect from firms with complex technologies to other firms in a region.

5. *Hypothesis H3:* Contextual factors, spatial spillovers, and agglomeration effects positively influence digital complexity. This suggests that the broader environment and concentration of related activities enhance a region's or organization's digital complexity.

6. *Hypothesis H4:* Contextual factors, spatial proximity and agglomeration, have a positive effect on technology adoption. The hypothesis argues that being in an innovation-oriented context with spatial and agglomeration advantages facilitates the adoption of new technologies.

7. *Hypothesis H5:* There is a reciprocal positive relationship between digital technology adoption and GDP per capita. This implies that not only does technology adoption contribute to higher GDP per capita, but also that regions with higher GDP per capita are more capable of adopting new technologies.

1.7 Research Contribution and Novelty

The research contribution and novelty of this dissertation are very important. The focus was on the complex dynamics between digital relatedness density, digital complexity, and web technology adoption across European regions. Here are the key highlights:

The dissertation provides a comprehensive analysis that explains and describes the complex and context-dependent relationships between digital complexity, productivity, and digital technology adoption. Moreover it advances the academic debate on effects of digital transformation by exploring the upper mentioned interconnected dynamics, contributing to a deeper understanding of the factors driving technology adoption and regional development from a ecosystem and economic geography perspective. The novel results focused on digital technologies, highlight the importance of fostering connected ecosystems. By adopting profound study approach to digital complexity, offering practical insights for policymakers and practitioners aiming to harness technological advancements for regional development. It looks on how the regional complexity influences, regional digital technology adoption, but also how following a path dependent approach affects adoption of new digital technologies

The novel dimension of this dissertation lie in its robust support for the hypothesis that a higher relatedness density significantly fosters the entry of related web technologies, emphasizing the role of cognitive proximity and interconnected ecosystems in regional innovation and technological adoption. Moreover it is the first time when the economic complexity and relatedness frameworks are applied to digital web technologies. Another aspect is that the study challenges preconceived notions about digital complexity, suggesting a paradox where regions with more advanced technologies might encounter diminishing returns in adopting new technologies as adoption requires higher capacity. Moreover, a spatial measurement of web technology adoption and used by firms was not performed. Such insights challenge the traditional understanding of digital adoption and highlight the need for a more detailed understanding of digital complexity's role in technology adoption and regional productivity.

1.8 Dissertation Structure

The dissertation undertakes a comprehensive examination of the entrepreneurial ecosystem and smart specialisation strategies, especially in the context of digital transformation and its implications for regional economic development. It begins with an extensive Literature Review, charting the evolution of the entrepreneurial ecosystem concept from its inception. This section meticulously dissects the framework and dynamics of these ecosystems, highlighting the critical roles of policy, finance, culture, and networks. It delves into the transformative impact of digital technologies, exploring how they reshape industries and foster the emergence of platform ecosystems.

In the Methodology chapter, the dissertation highlights its research design and analytical strategies, focusing on spatial panel fixed effects models to explore the interplay between digital complexity, productivity, and technology adoption across European regions. This methodological approach is critical for understanding spatial dependencies and the detailed relationships that underpin regional economic performance and the diffusion of digital technologies.

The narrative progresses to an analysis of Digital Complexity and Productivity, presenting empirical evidence to elucidate how digital technologies influence labor productivity. This chapter uncovers significant spatial spillovers, revealing the interconnected nature of regional economies and the paradoxical role of digital complexity in driving economic performance.

Later, the examination shifts towards Technology Adoption in the Digital Era, investigating the factors that support or impede the adoption of digital technologies. Through a detailed analysis, it identifies a paradox where regions of high digital complexity do not always lead in technology adoption, pointing towards the saturation effects and the importance of relatedness density.

The Role of Spatial Factors and Ecosystem Dynamics chapter further explores the geographical and economic factors shaping digital transformation. It provides insights into the core-periphery dynamics, highlighting how spatial factors and ecosystem dynamics are crucial in understanding the uneven distribution of digital technologies.

Concluding with the Policy Implications chapter, the dissertation synthesizes its findings, offering actionable insights for policymakers and regional planners. It advocates for comprehensive strategies that address both technological advancements and socioeconomic considerations, aiming to enhance regional competitiveness in the digital age. This chapter also sets the stage for future research, suggesting avenues for deeper exploration into the details of digital ecosystems and their broader economic implications.

2 Literature review

2.1 Entrepreneurial Ecosystems

The dissertation begins with a detailed look at the development and significance of entrepreneurial ecosystems theory and contextual factors. It traces the origins of the concept from the early individualistic views of entrepreneurship by scholars like Schumpeter (1934, 1943), the view of socialist entrepreneurship in Marx (2018), to the more contemporary ecosystem perspective emphasizing the evolution, interactions, networks, and contextual factors in an ecosystem (Tansley, 1935; Acs et al. 2017).

The concept of entrepreneurial ecosystems theory was introduced by Daniel Isenberg in his 2008 work, focusing on the obstacles companies encounter when expanding internationally because of cultural, regulatory, and institutional variations among countries (Isenberg, 2008). Later studies by Isenberg (2010, 2011) and Feld (2012) underscored the significance of government policies and regulations in fostering entrepreneurial environments to promote economic development.

A pivotal moment in this research direction was the holistic definition of entrepreneurial ecosystems by Acs et al. (2014) as the "dynamic, institutionally embedded interaction between entrepreneurial attitudes, ability, and aspirations, which drives the allocation of resources through new ventures" (p.119). This view regarding the ecosystems paved the way for the creation of the Global Entrepreneurship and Development Index (GEDI) to measure national entrepreneurship ecosystems across pillars like opportunity perception, startup skills, risk acceptance, networking, and cultural support.

In the dissertation, it is extensively discussed the entrepreneurial discovery process and the importance of high-growth firms (HGFs) for productive entrepreneurship (Baumol, 1990; Shane, 2009; Reynolds et al. 2014). It highlights how new entrants often drive radical innovations better than incumbents due to organizational inertia and the liability of newness (Teece, 1986; Christensen and Rosenbloom, 1995). HGFs are identified as early technology adopters, more productive and crucial for productivity and economic growth (Coad et al. 2014; Bosma et al. 2018). The websites of the high growth, highly technological firms are used as the object of this study.

In the examined literature of the dissertation a major attention is paid to the importance of place-based entrepreneurial ecosystems and the role of geography, proximity and localized endowment of capabilities (Qian et al. 2013; Stam and Welter, 2020). As motivation for the empirical part, it discusses how entrepreneurial activity and knowledge spillovers have a strong spatial dimension, influenced by factors like human capital, infrastructure, culture and amenities (Audretsch and Belitski, 2017; Fischer et al. 2022). And this spatial dimension is later impacting the process of digitalization. Similarly to the ecosystem, industrial districts, clusters and the co-location of complementary actors create supportive environments for entrepreneurs (Becattini, 2017; Amin and Thrift, 2009). The literature studies and recognises the need for a holistic approach to innovation, entrepreneurship and digitalization.

Moreover, the dissertation examines the impacts of digitalization on entrepreneurial ecosystems through the adoption of digital technologies and later development of platforms, AI, IoT and digital business models (Kenney and Zysman, 2016; Bădoi, 2020). Platforms are more seen as multi-sided markets enabling interactions between different user groups through network effects (Rochet and Tirole, 2003). Digital ecosystems, on the other hand, comprise interconnected actors collaborating for innovation and value co-creation, often orchestrated by ecosystem leaders (Gawer and Cusumano, 2014; Lang, 2019). However, this digital ecosystem cannot be separated from the physical and geographical aspects of a region.

Finally, the importance of benchmarking and tailoring policies to place specific ecosystem bottlenecks is emphasized in the dissertation for fostering entrepreneurship (Szerb et al. 2019). It is noted that ecosystem measurements should go beyond static indicators to capture the interdependencies and dynamics, resilience, and adaptability of entrepreneurial systems (Stam and Van de Ven, 2021). Existence evidence shows better entrepreneurial ecosystems have a positive relationship with increased venture capital, innovative startups and unicorns (Lafuente et al. 2022; Leendertse et al. 2021).

2.2 Evolutionary Economic Geography

2.2.1 Evolutionary Economic Geography and Relatedness Theory

Evolutionary economic geography (EEG) argues that the previous experiences, competencies, and knowledge acquired over time by individuals and firms in a particular place or region can represent current industrial occupation and lead to future industrial and development paths (Kogler 2015). It uses biological system terms like 'diversity', 'selection', 'resilience', and 'adaptation' to describe local ecosystems (Boschma 2017; Auerswald and Dani 2017).

The concept of relatedness states that regions are more likely to expand into technologies or industries aligned with their existing strengths, meaning developing new products, industries, technologies, and occupations related to their current capabilities (Hidalgo et al. 2007; Neffke et al. 2011; Boschma et al. 2015; Balland et al. 2019). Studies show that technologically related sectors allow for more knowledge spillovers and learning opportunities, leading to regional growth (Frenken et al. 2007; Boschma and Iammarino 2009).

On the other hand, an unrelated variety of technologies can also increase productivity in regions that have high absorptive capacity and business entry rates (Fritsch and Kublina 2018). At the firm level, while related variety increases incremental innovation, unrelated variety increases radical innovation probability (Solheim et al. 2018).

2.2.2 Specialization and Complexity

The specialization concept argues that the division of labour increases productivity and wealth (Smith 1887). At the same time, if a region uses its resources and capabilities rationally and chooses its industrial paths accordingly it will achieve higher productivity. However, excessive specialization can lead to lock-in and overdependence on other nations (Ali and Cantner 2020). A mix of diverse industries allows more production, innovation and path combinations (Gomory and Baumol 2000a).

Economic complexity frameworks explain cross-country income differences through the diversity and sophistication of a country's exports and products, reflecting its "capabilities" (Hidalgo and Hausmann 2009). Higher complexity is linked to lower income inequality in general but can increase inequality between labour groups (Hartmann et al. 2017; Ncanywa et al. 2021). It is expected that digital complexity will also increase the productivity of regions.

Technological complexity on the other hand considers a nation's patent activity across diverse categories to measure the knowledge complexity. And the more interdependent knowledge components the higher its technological complexity (Balland and Rigby 2017). Excessive specialization in complex technologies however risks lock-in, while moderately complex knowledge diffuses better as they are easier adopted (Sorenson et al. 2006).

2.2.3 Smart Specialization

The Smart Specialization Strategy (S3) aims to promote innovation and growth in EU regions by identifying research and innovation paths according to each region's entrepreneurial activities and capabilities (Foray et al. 2009). It pays attention to prioritization, accumulation of resources, modernization and diversification.

However, S3 implementation has been challenging for less-developed regions lacking a critical mass of capabilities, industrial diversity, quality governance and entrepreneurial climate (Capello and Kroll 2016; Morgan 2015).

Prioritizing new technological domains based on relatedness has been proposed (Balland et al. 2019), but this approach may be biased towards multinational exports (Hausmann 2013) and overlooks contextual factors like institutions and entrepreneurial discovery (Grillitsch 2016; Kirzner 1997).

The choice between specialization and diversification has trade-offs and has to be carefully considered. While specialization risks regional lock-in (Valdaliso et al. 2014), diversification can inhibit economies of scale (Foray 1997). A potential solution identified in the literature is specializing in short-cycle technologies that enable regions to capitalize on windows of opportunity from emerging innovations (Lee 2014; Christensen et al. 2007).So first regions may need to diversify and then specialize.

2.3 The Importance of Digitalization for Regional Innovation and Economic Growth

2.3.1 Digitalization and Digital Web Technologies

Digitalization refers to the transformation of socio-economic systems driven by adoption of digital technologies for servicies and software or digitization of industries like semiconductors and networks (Katz et al., 2014). Initial metrics of digitalization focused on internet/broadband access, but the focus has shifted to the effective usage of digital technologies and participation in the digital economies aimed to quantify and bridge the "second-level digital divide" (Hargittai, 2002; Blank et al., 2018).

Web technologies are the core infrastructure of platforms and online activity, enabling online communication, transactions and web innovation (Yoo et al., 2010; Tsalgatidou and Pilioura, 2002). They include coding languages, platforms for website creation, e-commerce, analytics etc. (Morris, 2015). Web technologies drive innovation across sectors (Melville et al., 2004), increase productivity (Brynjolfsson and Hitt, 2000), enable entrepreneurship by lowering entry barriers (Acs et al., 2021) and are transformative general-purpose technologies as they create new business models (Bresnahan and Trajtenberg, 1995).

2.3.2 Spatial Aspects of Digitalization

Though expected to diminish distance, or even the "death" of distance, studies show that local contexts significantly shape digital technology adoption and usage (Graham, 2013; Castells, 2010). Digitalization can reduce rural-urban inequalities but also reinforce existing disparities based on skills and usage (Van Dijk, 2020; Ragnedda and Muschert, 2013).

Digital technology diffusion is spatially constrained as the farther from adoption leaders, the slower the diffusion, and spatial spillovers may affect adoption (Comin et al., 2012). Proximity to tech hubs aids absorption due to knowledge spillovers (Jaffe et al., 1993). However, some decentralizing forces of digitalization are observed (Tranos and Ioannides, 2020). Urban agglomerations enable scale economies in digital infrastructure (Grubesic and Mack, 2015).

Spatial econometric models reveal knowledge spillover effects, digital investments or adoption of specific technology in one region benefits neighbours economically. But the concentration of these digital investments in urban areas risks uneven development (Arribas-Bel et al., 2019). Moreover, infrastructure challenges in rural areas also impact digital diffusion (Philip et al., 2015). This raises the need for empirically testing the importance of spatial factors for digitalization.

2.3.3 Digital Platforms and Local Embedding

Digital platforms enable new business models and entrepreneurial discovery by facilitating multi-sided interactions (Boudreau and Hagiu, 2009; Nambisan et al., 2019). While reducing physical frictions, they tend to enhance local agglomeration benefits cognitively by coordinating activities (Makadok and Coff, 2009).

Platform companies, acting as spatial intermediaries, hold significant influence over local economies, however, their function is more as the front-end of the economy (Graham, 2020). Their boundary choices based on factors like scope and platform design shape regional landscapes. But their actual functioning is also shaped by physical economic activity.

2.3.4 Significance of Web Technologies

Digital web technologies are pivotal enablers of innovation, value creation, data-driven decision-making and global connectivity (Nambisan, 2017; Zahra and Nambisan, 2012). It is claimed that they present opportunities for regional development by enabling niche exploitation, process efficiency, rural revitalization and decentralization (Autio et al., 2018).

However, their regional adoption, integration with entrepreneurial ecosystems and smart specialization strategies pose challenges and opportunities to be empirically examined.

2.3.5 Research Gaps

While digital technologies' transformative potential on regions is recognized (Kenney and Zysman, 2016), the detailed pathways of how digital complexity directly enhances regional productivity need empirical evidence (Acs et al., 2017; Autio et al., 2018). Moreover, a framework for digital web technology adoption is missing and it is not clear how digital technology adoption is integrated with entrepreneurial ecosystems and smart specialization strategies

The role of place-based factors in shaping digital technology adoption and adaptation across contexts remains little explored. Evidence on digital innovation strategies tailored to specific regional contexts is lacking.

Contradictions exist regarding digitalization's impact on regional inequality and the digital divide, necessitating further research into these complex relationships (Cohen and Kietzmann, 2014; Cairncross, 2002; Autio et al., 2018).

2.4 Research Design and Methodology chapter

This section presents a detailed and comprehensive approach towards analyzing the digital adoption divide across European regions, emphasizing the interplay between evolutionary factors and regional characteristics on technology adoption and subsequent economic growth. This section is meticulously crafted, employing a multifaceted methodology that includes the selection and geolocation of firms, identification and monitoring of web technologies, and the collection of technology adoption and contextual factors.

Methodology Overview The research utilizes Crunchbase to identify high-growth technology firms and startups, focusing on those at the forefront of digital innovation. This selection process is crucial for understanding regional disparities in technological adoption and its economic outcomes, with firms chosen based on their geographical location, industry sector, and website ownership.

In the case of identification and Monitoring of Web Technologies, the BuiltWith API tracks the adoption of digital web technologies by these companies, enabling a longitudinal study of technology diffusion across NUTS 2 European regions. This analysis is pivotal for examining Digital Complexity and Relatedness density across regions, identifying a spectrum of digital web technologies from basic utilities to advanced functionalities.

The study quantifies the adoption rate of selected web technologies, merging company data with technological usage information. It also integrates various contextual factors like the quality of government, infrastructure, and business sophistication to assess their influence on technology adoption.

Data Sources The thesis leverages data from diverse and comprehensive sources, ensuring a rich empirical foundation:

Crunchbase provides data on high-growth tech firms and startups, crucial for identifying firms at the innovation forefront. BuiltWith offers detailed records of technology deployment on web domains, enabling the study of technology diffusion. ARDECO supplies economic performance indicators such as GDP per capita and employment, vital for understanding the economic context. EUROSTAT and Quality of Government Institute contribute data on talent and governance quality, contextualizing the technological adoption within broader socio-economic frameworks. EU Regional Competitiveness Index (RCI) provides insights into the quality of infrastructure and business sophistication, influencing the adoption and effectiveness of digital technologies. Analytical Models The methodology incorporates sophisticated analytical techniques, including spatial econometric models, logistic models and the method of reflections, to explore the interconnectedness of digital web technologies within regions and their impact on economic outcomes like labor productivity. These models evaluate the probability of the entry of related web technologies in a given region and assess the impact of digital complexity on labor productivity or technology adoption, incorporating various independent variables and utilizing fixed effects to account for unobserved heterogeneity.

This comprehensive examination, combining rich data sources with advanced empirical models, underlines the thesis's exploration of digital adoption divides and the significant role of regional characteristics and evolutionary factors in shaping digital technology adoption and economic growth. Through this approach, the research aims to contribute valuable insights to the discourse on digitalization and regional development, offering a detailed understanding of the factors influencing digital technological advancement and economic dynamics across European regions.

3 Results

3.1 The role of relatedness in digital technology adoption- regional level

The following figure represents a network visualization of digital web technologies, where each node corresponds to a different technology. The size of each node is indicative of the eigenvector centrality of the respective digital web technology. Eigenvector centrality is a measure of the influence of a node within a network; larger nodes in this context imply that a technology has a greater influence within the web of digital technologies, likely due to its widespread use or integration with other technologies.

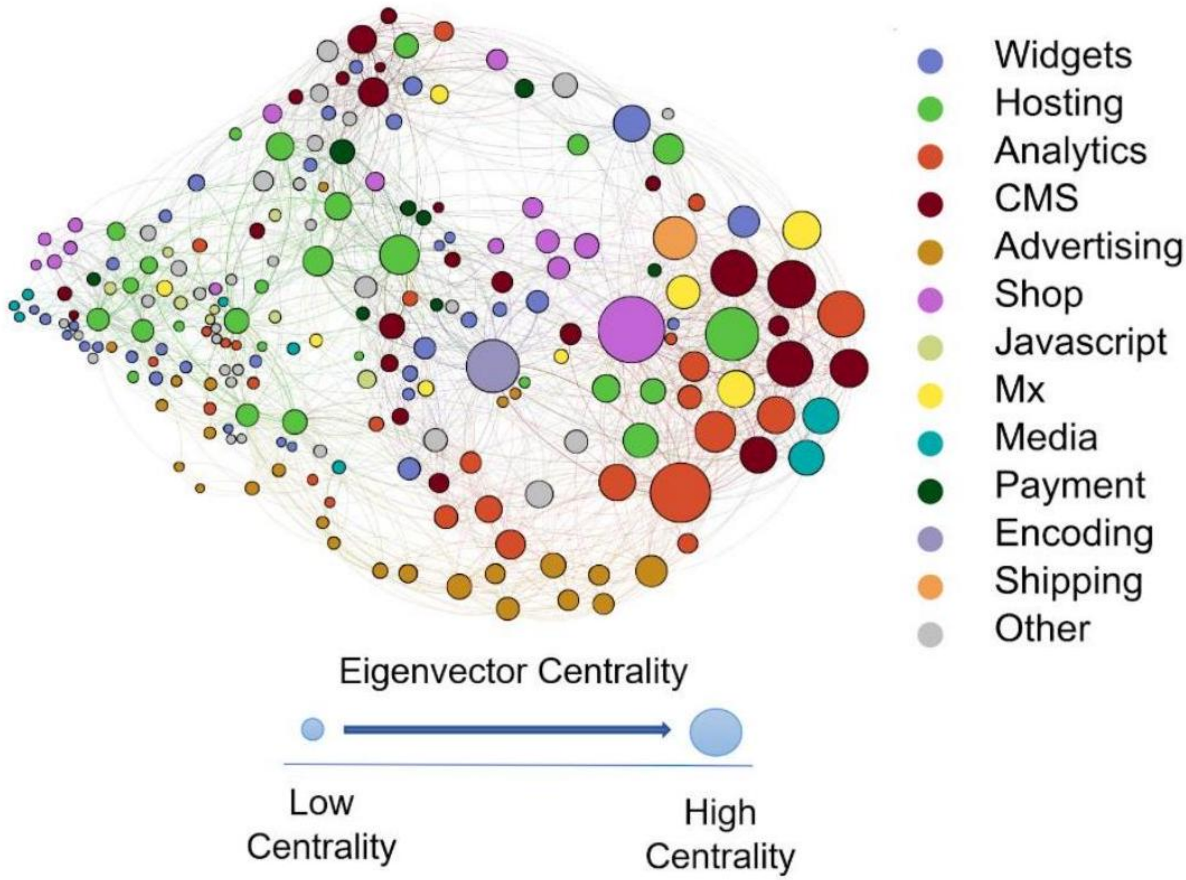

Figure 2: The digital space of the web technologies. Source: Authors' own elaboration.

The relatedness between web technologies is depicted through the lines connecting the nodes. A greater number of lines between technologies indicates a higher degree of relatedness, suggesting that these technologies are often used together or have complementary functionalities. For instance, technologies related to analytics, content management systems (CMS), hosting, and shopping could be more interconnected due to their joint role in the ecosystem of an e-commerce platform.Technology space analysis can help to identify key enabling technologies that drive digital industry coalescence and new digital industry emergence (Trincado-Munoz et al. 2023). This analysis also elucidates which technologies singularly influence industry digitalization and which technologies operate synergistically as a system.

The colors of the nodes differentiate the technology groups, providing a visual segmentation of the various categories like CMS, advertising, media, payment, etc. This color-coding helps in quickly identifying clusters of related technologies within the network, showing how certain categories of technologies are central to the digital ecosystem.

Table 1 represents the results of logistic regression models that predict the likelihood of entry of related web technologies in a given region, with ' 1 ' indicating the entry. The positive coefficients Relatedness density across all models indicate that a higher relatedness density significantly increases the likelihood of entering related web technologies. This effect remains robust even after controlling for other variables and fixed effects in models (3) and (4). The coefficient of GDP per capita is positive and significant in model (2), suggesting that regions with higher GDP per capita are more likely to see the entry of related web technologies. However, in the full model (3), this turns negative, indicating that when other factors are controlled, higher GDP per capita might not necessarily lead to the entry of related web technologies. In the case of Total employment, this variable is not significant in models (2) and (3), and it has a negative coefficient in the full model(4), suggesting that higher employment might be associated with a lower likelihood of entry of related web technologies when controlling for other factors. This factor may indicate a lock in effect which takes place at regional level, or so-called entrenchment of personnel. As the majority of individuals in a region are employed by a couple of industries, they do not have the capacity to diversify and introduce new related projects and web technologies.It's conceivable that the interaction between digitalization and job markets is bidirectional, where not only does digitalization transform job markets, but the dynamics of job markets also affect the uptake of corresponding digital technologies.

The positive and significant Population density coefficient in model (2) suggests that more densely populated regions are more likely to see the entry of related web technologies. The significance disappears in the full model without fixed effects but reappears positively in the full model with fixed effects.This corresponds with Jacobs' (1969) concept of externalities and the subsequent cluster theory, which suggest that the variety of skills and ideas present in densely populated urban areas act as catalysts for innovation. This concept is equally valid for the entry of web technologies. As expected, the positive coefficients of Patent applications in models (3) and (4) indicate that regions with more patent applications are more likely to see the entry of related web technologies, suggesting a relationship between innovation and the entry of related digital web technologies.This finding aligns with the research from Acs, Anselin, and Varga (2002), which suggests that regions with higher patenting activity are likely to be more innovative. However, this current finding contributes to the discussion on the relationship between the digital and physical worlds, challenging the idea of the "death of space." It shows that, contrary to expectations, spatial relevance has not diminished in the digital era.

Table 1: Related entry model: logit models.

	Dependent variable: Related Entry (= 1)			
	(1) Baseline	(2) Controls	(3) Full model	(4) Full model Fixed Effects
Constant	-1.752^{***} (0.00913)	-1.822^{***} (0.0154)	-1.752^{***} (0.0102)	
Relatedness density	0.0281^{***} (0.000869)		0.0300^{***} (0.000936)	0.0270^{***} (0.00112)
(log) GDP/cap		1.929^{**} (0.858)	-1.163^{*} (0.676)	0.457 (1.183)
(log) Total population		1.713^{**} (0.846)	-0.996 (0.679)	-9.238^{***} (1.312)
(log) GVA		-1.798^{**} (0.844)	0.920 (0.665)	0.293 (1.152)
(log) Total employment		0.129 (0.124)	-0.0749 (0.0800)	-1.155^{***} (0.289)
(log) Population density		0.0474^{***} (0.0161)	0.0159 (0.0113)	7.055^{***} (1.279)
(log) Patent applications		0.00486 (0.0146)	0.0957^{***} (0.0113)	0.0810^{***} (0.0302)
Observations	218,268	218,268	218,268	87,732
R-squared (Pseudo)	0.02	0.003	0.02	-
Region-Tech Fixed Effects	NO	NO	NO	YES

Continued on next page

Table 1 continued from previous page

Year FEs	NO	NO	NO	YES

Notes: All predictor variables have been standardized around the mean and are delayed by one time period. Standard errors that are robust to heteroskedasticity (and clustered by region) are presented in brackets for all models except the two-way fixed effects (4). Coefficient values reach statistical significance at the $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$ levels.
Source: Authors' own elaboration.

3.2 Digital Complexity and Technology Adoption

The following figure illustrates the degree of digital web complexity in European regions classified as NUTS 2 level. The map uses a color gradient to indicate the varying degrees of digital complexity, with different shades representing different levels. The data reveals that areas denoted by dark green have the most intricate digital infrastructure, with scores ranging from 90 to 100. It is probable that these areas possess sophisticated digital infrastructures, considerable levels of digital literacy, and resilient digital economies. Digital complexity is moderate to high in regions denoted by lighter green hues, where scores range from 50 to 89. This indicates that the digital environment is highly developed, however not to the same extent as the darkest green regions. Yellow regions, meanwhile, indicate a moderate level of digital complexity, as indicated by scores ranging from 30 to 49. These regions may be in the midst of digital infrastructure development or face gaps in digital literacy and access. Lastly, areas colored pale yellow to white, which receive scores ranging from 0 to 29 , represent reduced digital complexity. This implies that these areas can encounter difficulties pertaining to digital infrastructure, accessibility, or literacy.

Initially, the positive coefficients for digital complexity in the pooling Ordinary Least Squares (OLS) models indicate a general positive influence of digital complexity on productivity, supporting the acceptance of Hypothesis H2a. This finding aligns with the hypothesis that regions or organizations with higher digital complexity are hypothesized to exhibit higher productivity levels.

However, as seen in the following table, the transition to spatial panel fixed effects models,

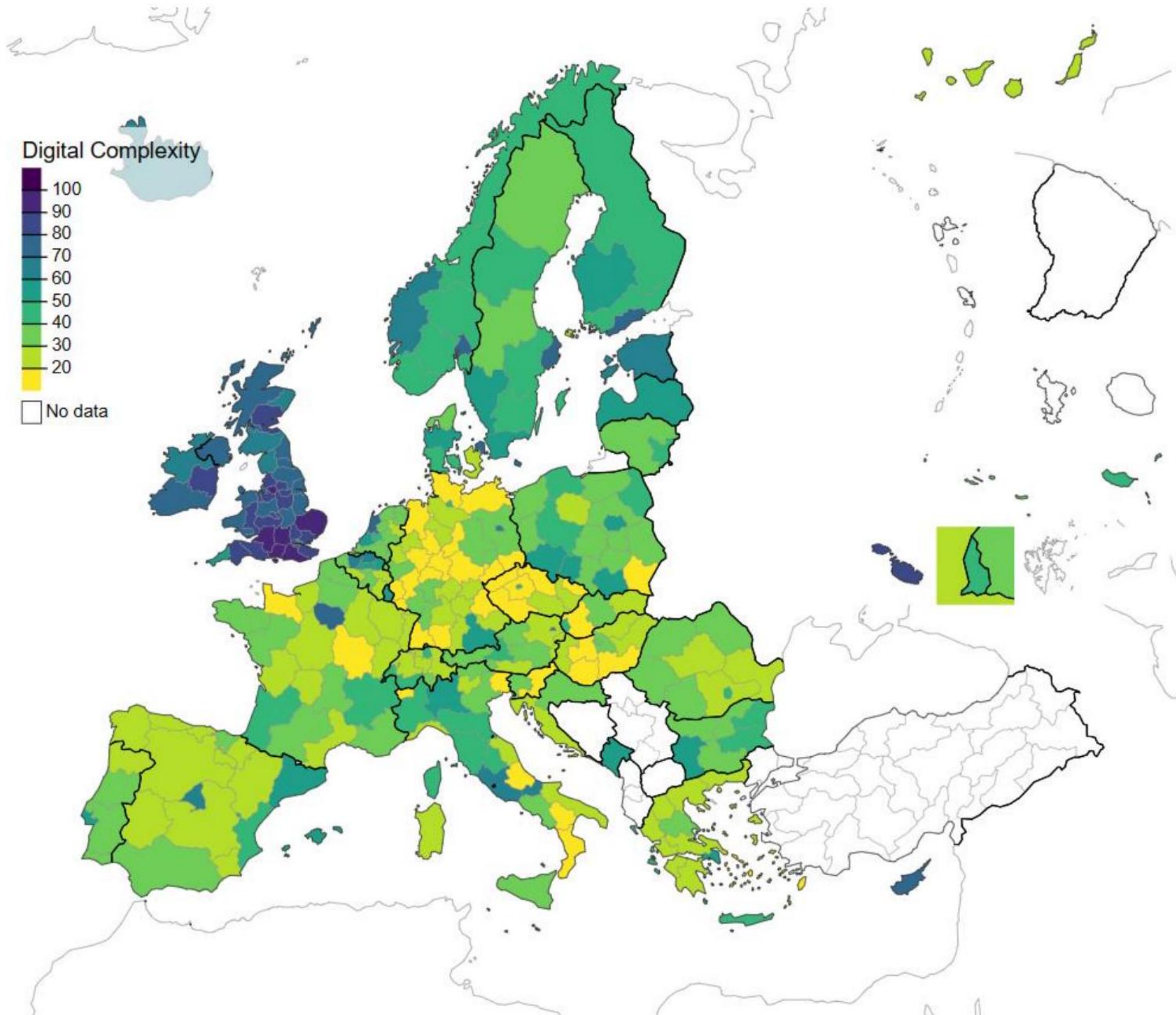

Figure 3: Digital complexity in European regions classified at the NUTS 2 level. Source: Authors' own elaboration.

which account for regional and temporal variations, reveals a more complex relationship. The mixed results, where digital complexity initially shows a positive impact on productivity but then demonstrates negative coefficients in models adjusted for spatial and temporal dynamics suggest that the relationship between digital complexity and productivity is contingent upon specific regional characteristics and the broader economic context.

This complexity, particularly the negative coefficients observed in more refined models, may imply that while digital complexity contributes to productivity, its effects are not universally positive across all regions and circumstances. Factors such as the maturity of the digital infrastructure, the adaptability of the workforce, and the existing economic structure of a region

Table 2: Spatial study of the effect of Digital Complexity on productivity

	Dependent variable: log (Productivity)			
	(1)	(2)	(3)	(4)
rho	0.5473^{***}	0.4310^{***}	0.1945^{***}	$0.3021***$
	(0.0237)	(0.0279)	(0.0322)	(0.0302)
(Intercept)	10.6589^{***}	2.3326^{***}	–	–
	(0.0345)	(0.0798)	–	–
log (Digital complexity)	0.0022^{***}	–	-0.0004^{**}	-0.0003^{***}
	(0.0006)	–	(0.0001)	(0.0001)
log (GDP/cap)	–	0.8509^{***}	–	0.7752^{***}
	–	(0.0085)	–	(0.0118)
log (Population density)	–	-0.0278^{***}	-0.0673	0.1953^{***}
	–	(0.0028)	(0.0506)	(0.0259)
log (Patent applications)	–	-0.0012	0.0438^{***}	0.0040
	–	(0.0028)	(0.0055)	(0.0028)
log (Productivity spatial lag)	–	–	0.8221^{***}	$0.1478***$
	–	–	(0.0194)	(0.0142)
Region FE	No	No	Yes	Yes
Time FE	No	No	Yes	Yes
Observations	1575	1575	1505	1505

Notes: The model in use is a spatial panel fixed effects model, controlling for time and space heterogeneity. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$..

may play critical roles in determining the extent to which digital complexity can translate into productivity gains.

Given these considerations, it would be more accurate to state that we partially accept Hypothesis H2a. This partial acceptance acknowledges the positive impact of digital complexity on productivity under certain conditions, while also recognizing the limitations and variability of this impact across different spatial and temporal contexts. The evidence suggests that the influence of digital complexity on productivity is significant but complex, influenced by a multitude of factors that can enhance or mitigate its effectiveness.

To prove the idea that the geography and local factors shape the technology adoption and is not the technology that shrinks the space you can see the following Figure No.4. Let's focus specifically on the spatial distribution of live chat technology adoption in Eastern Europe and the Central-West/South regions. In Eastern Europe, including countries like Poland, the Czech Republic, Slovakia, Romania, Bulgaria, and the Baltic states, the LISA map indicates High-High

(HH) associations, which are shown in dark purple. This suggests that these regions have high levels of live chat technology adoption and are also surrounded by regions with similar levels of adoption.

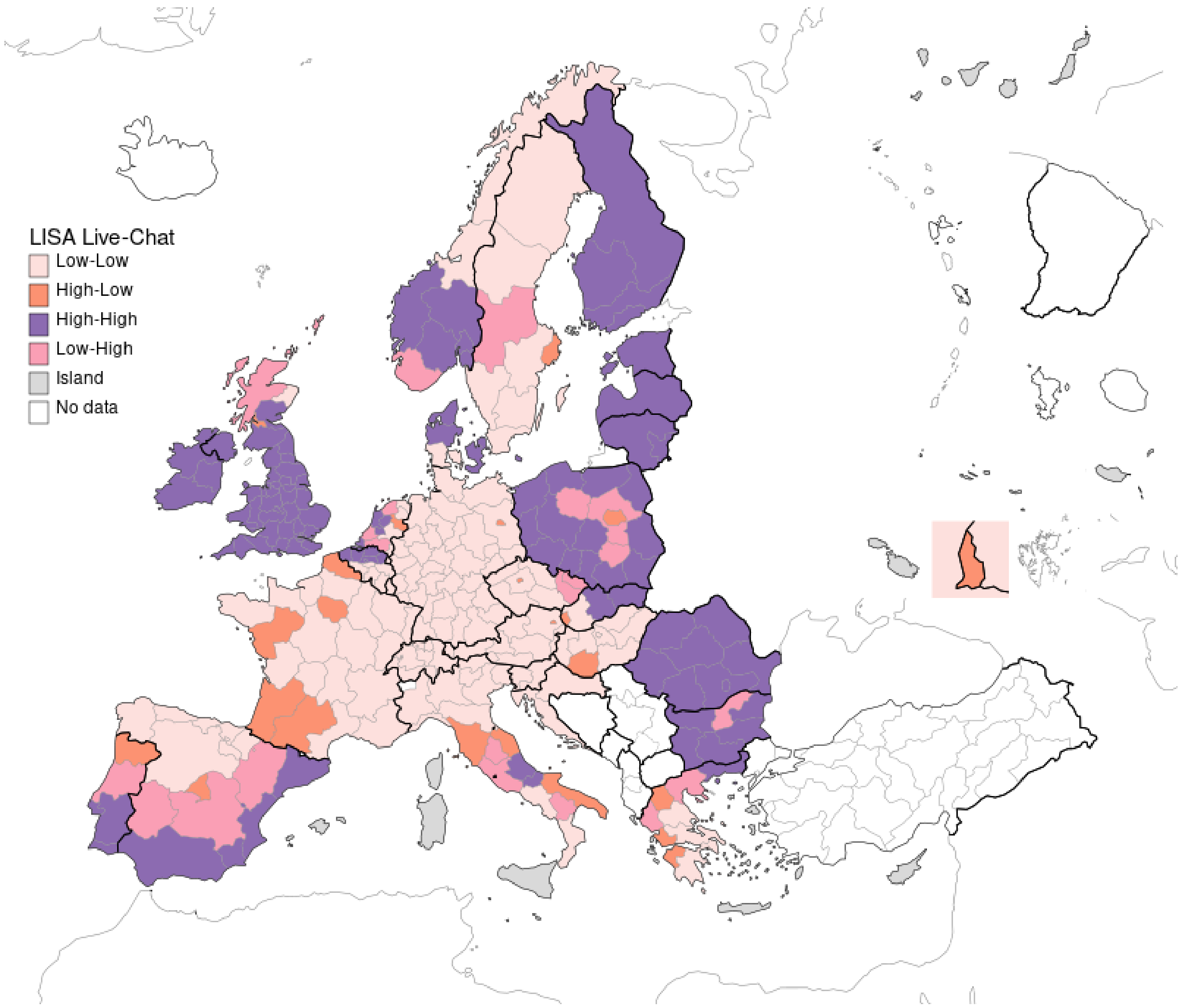

Figure 4: Local Indicators of Spatial Association (LISA) for the live-chat web technology adoption. Source: Authors' own elaboration.

Comparatively, Central-West or Central-South Europe may show different patterns, potentially mixing High-High and Low-High (LH) associations. The LH associations could indicate that while some central areas have high adoption, they are adjacent to areas with lower adoption levels, which may reflect varying economic conditions, the presence of rural areas, or differing priorities in technological investments. When comparing live chat technology to JavaScript libraries, we can surmise that the former's adoption goes beyond the mere presence of technological solutions. This indicates a strategic choice to enhance customer interaction and improve service delivery. Live chat systems involve a complex blend of technology and human interaction, requiring more sophisticated infrastructure, higher digital literacy, and potentially more investment in customer service. The high levels of adoption in Eastern European countries suggest that these regions have not only caught up with but might be leading in implementing complex web technologies for business communications solutions. However this could be also associated with the region's growing role as a hub for offshoring activities, including client service centers and call centers.The presence of offshoring activities, particularly those focused on customer service and live chat, may explain the high adoption rates of live chat technologies in the region.

Interpreting the extensive data from the following table, offers a comprehensive insight into the dynamics of technology adoption, the interplay of digital complexity, relatedness density, socioeconomic variables of the ecosystem and their collective impact on economic output. The analysis of control variables across different technologies, including the Javascript library and Live Chat, unveils a more clear narrative about the relationship between various contextual factors and technology adoption. These factors as digital complexity, relatedness density, population density, patent applications, business sophistication, talent, quality of governance, and quality of infrastructure show a complex picture of the ecosystem within which new web technologies are adopted or improved.

Digital web technologies are inherently more scalable, subject to rapid evolution, and often require less capital investment for deployment compared to physical technologies. This distinction influences how various factors like digital complexity, relatedness density, and the quality of infrastructure impact their adoption.

When considering digital complexity, the negative association with technology adoption could reflect not just integration challenges but also the rapid pace of change in the digital domain. Regions with highly complex digital landscapes may struggle to adopt new web technologies not because of saturation alone but due to the need for constant updates and the challenge of keeping up with evolving standards and practices. Moreover, having an environment with a majority of complex technologies makes it more difficult for other firms to adopt them as that requires time and more investment in talent and capabilities.

The positive impact of relatedness density on the adoption of digital web technologies is particularly pronounced in this context. The interconnectedness and cognitive proximity facilitated by relatedness density are crucial in a digital ecosystem where technologies often build upon existing platforms and frameworks. This interconnectedness enables faster diffusion and integration of new digital solutions, leveraging shared knowledge and existing digital infrastructures.

Contrary to the expectations, Population density has an insignificant effect suggesting that agglomeration forces do not influence the adoption of digital web technologies. Also, the role of patent applications in the adoption of digital technologies suggests that innovation in the industrial space may not always lead directly to widespread web technology adoption.

Business sophistication and talent emerge as critical enablers of technology adoption in the digital domain. The capacity to navigate the complex landscape of digital technologies and integrate them into business processes or product offerings is a key determinant of success. The availability of skilled labour, knowledgeable in the latest digital tools and practices, is indispensable for leveraging on adoption and use of these digital technologies effectively.

Lastly, the quality of governance and infrastructure plays a foundational role in the adoption of digital technologies. Effective governance that supports digital innovation, through policies that encourage internet access, data protection, and digital education, directly influences the adoption of web technologies. Similarly, high-quality digital infrastructure is a prerequisite for the deployment and effective use of these web technologies, in a similar way as for physical technologies.

Table 3: The Influence of Digital Complexity and Relatedness on Technology Adoption

	Dependent variable: TA (Technology Adoption)									
	Ad analytics	Javascript library	Affiliate programs	Marketing automation	Audience measurement	Application performance	Live chat	CMS	Currency	Framework
Digital complexity	-0.001^{***}	-0.003^{***}	-0.001^{***}	-0.001	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.002^{***}	-0.002^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log(RelatednessDensity)	0.019^{***}	0.265^{***}	0.006^{***}	0.034^{***}	0.135^{***}	0.136^{***}	0.089^{***}	0.017^{***}	0.045^{***}	0.109^{***}
	(0.002)	(0.008)	(0.002)	(0.004)	(0.006)	(0.007)	(0.004)	(0.001)	(0.010)	(0.010)
log(Population density)	0.001	-0.005	0.001	-0.002	-0.002	-0.002	-0.001	-0.001	-0.005	0.001
	(0.001)	(0.004)	(0.001)	(0.002)	(0.003)	(0.003)	(0.002)	(0.001)	(0.005)	(0.005)
Patent Applications	-0.001	-0.001^{*}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.001^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Business Sophistication	0.037^{***}	0.496^{***}	-0.017^{***}	-0.001	0.090^{***}	0.117^{***}	-0.058^{***}	0.004	-0.166^{***}	0.066^{***}
	(0.005)	(0.019)	(0.005)	(0.010)	(0.015)	(0.016)	(0.010)	(0.003)	(0.026)	(0.023)
Talent	0.003^{***}	0.010^{***}	0.002^{***}	0.011^{***}	0.003^{***}	0.005^{***}	0.010^{***}	0.001^{***}	0.011^{***}	0.024^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Quality of Governance	-0.007	-0.161^{***}	0.010	0.122^{***}	-0.010	0.015	0.045^{**}	0.047^{***}	0.421^{***}	0.316^{***}
	(0.012)	(0.042)	(0.011)	(0.023)	(0.034)	(0.035)	(0.022)	(0.006)	(0.056)	(0.051)
Quality of Infrastructure	0.033^{***}	0.063^{**}	0.023^{***}	0.155^{***}	0.047^{**}	0.055^{**}	0.138^{***}	0.007^{*}	0.157^{***}	0.349^{***}
	(0.007)	(0.026)	(0.007)	(0.014)	(0.021)	(0.022)	(0.013)	(0.004)	(0.035)	(0.032)
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	No	No	No	No	No	No	No	No	No
Observations	2,013	2,088	2,024	2,066	2,088	2,088	2,077	1,980	2,088	2,088
R^2	0.480	0.848	0.161	0.585	0.507	0.537	0.675	0.325	0.221	0.653
Adjusted R^2	0.426	0.832	0.073	0.542	0.455	0.488	0.641	0.255	0.140	0.617
F Statistic	210.184^{***} (df = 8; 1822)	$1,320.852^{***}$ (df = 8; 1890)	43.798^{***} (df = 8; 1832)	329.933^{***} (df = 8; 1870)	242.500^{***} (df = 8; 1890)	273.658^{***} (df = 8; 1890)	488.413^{***} (df = 8; 1880)	108.014^{***} (df = 8; 1792)	66.962^{***} (df = 8; 1890)	445.377^{***} (df = 8; 1890)

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.All models are panel linear models estimated using the 'plm' package in R with a 'within'(fixed effects) model specification and individual effects. Dataset corresponding to specific technology: Ad Analytics,Javascript, Affiliate Programs, Marketing Automation, Audience Measurement, Application Performance, Live Chat, CMS, Currency, and Framework. Regional fixed effects are included in all models, while time fixed effects are not considered.

The following models in Table 4, looks into the combination of technology adoption with digital complexity and relatedness density, especially when examining Javascript library and Live Chat technologies, and unveils that a complex interplay between these factors significantly affects the spread of new digital tools within regions and regional economies. This intricate relationship, as outlined in the provided data, gives us a deeper understanding of how the adoption of emerging technologies is shaped by the pre-existing digital landscape and the network of technological capabilities that pervade a given area.

The analysis of the interaction between technology adoption and digital complexity, as well as relatedness density, particularly with respect to Javascript library and Live Chat technologies, demonstrates the detailed mechanisms through which the adoption of new digital web technologies is influenced by and, in turn, impacts regional economies. This exploration, grounded in the provided models, delineates the complex interactions between the existing digital infrastructure, the network of technological capabilities, and the economic outputs of regions.

In regions with advanced digital complexity, the adoption of Javascript library technologies not only integrates seamlessly into the existing digital ecosystem but also signifies a positive correlation with economic indicators such as GDP per capita. The implication is that in areas where the digital infrastructure is robust, the introduction of new technologies like Javascript libraries not only finds a conducive environment for adoption but also contributes to economic growth. This relationship underscores the importance of a well-established digital foundation in fostering technological innovation and diffusion, thereby enhancing the region's economic performance.

Similarly, for Live Chat technologies, a positive interaction with digital complexity suggests that regions with sophisticated digital infrastructures are better positioned to leverage these technologies effectively. The adoption of Live Chat technologies in such regions does not merely benefit from the pre-existing digital environment but also plays a role in further economic development, highlighting the reciprocal relationship between technological adoption and economic advancement.

The interaction between technology adoption and relatedness density offers insights into how the interconnectedness within a region's technological ecosystem facilitates the adoption of new technologies and influences economic outcomes. For the Javascript library, a positive coefficient indicates that regions with a dense network of related technologies and knowledge domains are more adept at incorporating new technologies, which in turn can drive economic growth. The presence of related technologies and knowledge bases not only eases the adoption process but also contributes to the region's economic dynamism by fostering an environment conducive to innovation and collaboration.

For Live Chat technologies, the interplay with relatedness density similarly reflects a region's capacity to assimilate and exploit these technologies based on its network of related capabilities. A positive interaction suggests that regions rich in interconnected technologies and competencies not only facilitate the adoption of Live Chat technologies but also leverage these technologies to boost economic performance. The collective knowledge and cognitive proximity inherent in such regions provide a fertile ground for innovation diffusion, which is instrumental in driving economic development.

This comprehensive analysis reveals that the adoption of digital web technologies like Javascript libraries and Live Chat is significantly shaped by the digital complexity and relatedness density of regions. Moreover, it highlights the critical role these factors play in influencing regional economic outputs. High digital complexity and relatedness density not only provide the necessary infrastructure and collaborative framework for technology adoption but also have a profound impact on economic growth, underscoring the intertwined nature of digital technological innovation, diffusion, and economic development. Thus, understanding and harnessing the interaction between technology adoption, digital complexity, and relatedness density is pivotal for fostering regional economic advancement in the digital age. It emphasizes the need to consider both the structural and relational dimensions of a region's technological ecosystem to fully grasp and encourage the widespread adoption of novel digital technologies.

Moreover, analysing Table 11 and 12 in the annexes reveals interesting findings. First in Table 11 about the Core-Periphery Dynamics. The analysis demonstrates that being in a core or periphery region significantly affects technology adoption rates, with core regions not always leading in the adoption of new technologies like Javascript library and Live Chat. This finding challenges traditional notions of innovation diffusion, suggesting that peripheral regions may also be active participants in adopting certain technologies, possibly due to specific needs, niche markets, or the presence of unique ecosystems that support such adoptions. And in the second case about Spatial Spillovers.The significant positive values of ρ across many models in Table 12 indicate that technology adoption in one region is likely influenced by the adoption rates in neighboring regions, highlighting the importance of spatial spillovers. This phenomenon is particularly pronounced in the adoption of the Javascript library and Live Chat technologies, where spatial dependencies suggest that regions do not operate in isolation but are part of a broader, interconnected technological landscape.

The examination of Hypotheses 3 and 4 brings to light intricate dynamics within the adoption and influence of digital technologies across regions. For Hypothesis 3, the findings suggest a partial acceptance. The influence of contextual factors on digital complexity and relatedness density is evident but manifests in complex and sometimes counterintuitive ways. While certain factors like quality of infrastructure and business sophistication positively influence digital complexity, suggesting that a well-developed infrastructure and a sophisticated business environment are conducive to enhancing digital complexity, other factors do not uniformly lead to increased digital complexity. This partial acceptance indicates that while some contextual factors are pivotal in fostering a complex digital landscape, not all factors contribute equally, and the overall influence is not entirely clear.

Hypothesis 4, on the other hand, is fully accepted. The analysis brings to the forefront the critical role of geographical factors and spatial spillovers in the adoption of technology. The analysis underscores the significance of geographical factors and spatial spillovers in technology adoption, with core-periphery dynamics and the presence of spatial autocorrelation (ρ) playing crucial roles. This acceptance highlights the enduring importance of geography in shaping technological landscapes, even in the digital age. The acceptance of Hypothesis 4 underscores the enduring relevance of geographical considerations in understanding and fostering technology adoption, even in the increasingly digital and interconnected world.

Table 4: The impact of contextual variables and technology adoption on Digital Complexity, Relatedness and the Economic Output

	Dependent variable:						
	Digital Complexity	Relatedness Density	log(GDP/cap)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Technology Adoption				−0.158***	−0.156***	0.222***	−0.400***
Digital Complexity				−0.003***		−0.001***	
Relatedness Density					−0.002**		0.001
log (Population Density)	-0.726	0.239	-0.004	-0.003	-0.004	0.001	0.002
Number of Firms	−0.010**	0.001	0.001***	0.001***	0.001**	-0.001	−0.001**
Business Sophistication	−26.325***	−5.777***	−0.311***	−0.352***	−0.313***	−0.283***	−0.256***
Existent Technologies	0.202***	0.025	0.001	0.001	0.001	-0.001	-0.001
Technological Readiness	−17.893***	−9.063***	-0.032	-0.012	0.008	-0.019	0.004
Patent Application	0.001	0.002***	0.001	0.001***	0.001*	0.001***	0.001***
Quality of Infrastructure	−21.844***	−4.524***	−0.114***	−0.131***	−0.114***	−0.156***	−0.154***
Quality of Governance	−20.402***	−15.693***	0.055	0.027	0.064*	0.053	0.087**
log(Total Employment)	11.822	-0.743	0.554***	0.503***	0.517***	0.522***	0.479***
Talent	1.222***	0.088**	−0.006***	−0.007***	−0.007***	−0.006***	−0.008***
Technology Adoption*Digital Complexity				0.003***		0.002*	
Technology Adoption*Relatedness Density					0.006***		0.023***
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Effect	Two-Ways	Two-Ways	Two-Ways	Two-Ways	Two-Ways	Two-Ways	Two-Ways
Observations	2,088	2,088	2,090	2,088	2,088	2,077	2,077
R^2	0.119	0.104	0.212	0.237	0.240	0.228	0.254
Adjusted R^2	0.021	0.004	0.124	0.150	0.154	0.140	0.170
F Statistic	25.315***(df = 10; 1878)	21.713***(df = 10; 1878)	50.468***(df = 10; 1880)	44.701***(df = 13; 1875)	45.625***(df = 13; 1875)	42.282***(df = 13; 1865)	48.906***(df = 13; 1865)

Notes: The dependent variables are Digital Complexity, Relatedness Density' log(GDP/cap) '. Dataset corresponding to specific technology: Javascript library (Models 4 and 5) and Live Chat (Models 6 and 7). $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

4 Discussion and Conclusion

4.1 Discussion

This dissertation delves into understanding the complex interactions between relatedness density, digital complexity, and technology adoption across European regions, elucidating the dynamics of digital web technology evolution and adoption and its spatial distribution in EU NUTS regions. Moreover, it looks at how place-specific factors interact with digital web technology adoption. I aimed at building the literature and empirically studying the following Hypothesis:

Hypothesis H1a: *There is a positive relationship between relatedness density and related entry. In the case of web technologies high relatedness density, indicates a closer knowledge relationship between existing and new technologies. Relatedness density is expected to enhance the likelihood of related entry, where firms in regions enter new digital technological domains that are closely related to their previous capabilities.*

My investigation provides robust support for Hypothesis H1a, showing that higher relatedness density significantly increases the odds of the entry of related web technologies. This finding emphasizes the importance of cognitive proximity and interconnected entrepreneurial ecosystems in regional innovation and technological advancement, aligning with the theoretical frameworks of evolutionary economic geography and relatedness theory. It suggests that regions characterized by a dense network of existing and new technologies characterized by higher relatedness density are more keen on navigating the intricacies of technological evolution and adopting new business models or adopting new web technologies, leveraging these connections for sustained economic growth and innovation. Moreover, this should warn us regarding the weak capabilities of other regions, as they may be trapped in the incapacity to adopt new technologies without existing capabilities.

Hypothesis H1b: *There is a positive relationship between relatedness density and technology adoption. High relatedness density, indicating a closer relationship between existing and new technologies, is expected to facilitate technology adoption.*

In this case, the acceptance of Hypothesis H1b reinforces the importance of relatedness density in facilitating digital technology adoption. Regions with higher relatedness density exhibit a greater propensity for adopting new technological domains that are closely related to their existing capabilities. This highlights the need for strategic regional smart specialization policies that promote environments where knowledge and technologies can easily be interconnected and recombined. In a similar line to the Schumpeterian "New combinations".Similar to the framework proposed in this dissertation. Therefore enhancing the firm digitalization, innovative capacity, and competitiveness of EU regions in the digital age.

Hypothesis H2a: *Digital complexity positively influences labor productivity. Regions with higher digital complexity are hypothesized to exhibit higher productivity levels. When firms are digitized and have complex web technologies they are expected to be more productive, therefore influencing the overall regional productivity.*

Hypothesis H2b: *There is a positive relationship between digital complexity and technology adoption. Higher levels of digital complexity within a region are expected to lead to greater technology adoption rates. Here it is expected a spillover effect from firms with complex technologies to other firms in a region.*

However, my analysis presents a distinct picture when examining the role of digital complexity. Contrary to the expected positive relationship hypothesized in H2a by digital complexity on productivity, and in H2b by digital complexity on technology adoption, the empirical evidence reveals a more complex and sometimes inverse relationship. Higher levels of digital complexity, rather than straightforwardly translating to higher rates of technology adoption, show a paradox where regions with advanced digital ecosystems and complex technologies encounter lower rates of adoption of new digital technologies. This paradox highlights the complexities of navigating highly developed digital environment and calls for a careful study of digital complexity's role in technology adoption. While I can suggest that when a region has more complex technologies this makes it harder for other firms to adopt them and requires higher capacities, this needs to be further investigated. This challenges preconceived notions and underscores the potential for saturation effects and compatibility barriers, suggesting that increased digital complexity does not uniformly lead to higher digital technology adoption rates or enhanced productivity.

In general, this analysis not only reaffirms the essential role of relatedness density in enhancing web technology adoption and facilitating the entry of related web technologies but also sheds light on the negative relationship between digital complexity and digital technology adoption. The findings contribute to a deeper understanding of the factors influencing digital web technology adoption and regional development through the digitalization of smart specialization frameworks. It suggests a complex and context-dependent relationship between digital complexity, productivity, and technology adoption. This enlarges the academic discourse on path dependency and what factors inhibit digital technology adoption and provides actionable insights for policymakers and practitioners. The dissertation one more time underscores the importance of fostering an ecosystem that nurtures innovation and leverages technological advancements for all types of firms and economic benefits and not solely for competitive advantage.

Hypothesis H3: *Contextual factors, spatial spillovers, and agglomeration effects positively influence digital complexity. This suggests that the broader environment and concentration of related activities enhance a region's or organization's digital complexity.*

Hypothesis H4: *Contextual factors, spatial proximity and agglomeration, have a positive effect on technology adoption. The hypothesis argues that being in an innovation-oriented context with spatial and agglomeration advantages facilitates the adoption of new technologies.*

The next part of the dissertation investigates the factors influencing digital complexity and technology adoption, Hypotheses 3 and 4 examine the role of contextual factors, including spatial considerations and agglomeration effects. Hypothesis 3 states that these contextual factors positively influence digital complexity, suggesting that a developed business environment and concentration of related activities enhance a region's digital complexity. Moreover, it also emphasises the importance of geographical proximity the agglomeration of industries and the quality of institutions in cultivating a developed digital infrastructure and ecosystem. The acceptance of this hypothesis highlights the significance of spatial arrangements, spillovers, and the density of technological and industrial clusters in enhancing digital capabilities within a region.

In a similar manner, Hypothesis 4 explores the impact of spatial proximity and agglomeration economies on web technology adoption. Technology adoption is the share of firms that adopt a specific web technology in a specific region. It states that being in a region with a developed environment and gaining from spatial and agglomeration advantages facilitates the adoption of new technologies. This enhances the understanding that clusters of interconnected firms, institutions, and industries create a dynamic entrepreneurial environment where knowledge spillover, collaboration, and innovation thrive. And when these environmental aspects are working, this accelerates the diffusion and adoption of new web technologies. Moreover, the visible spatial autocorrelation effects indicate an interdependence between neighbouring regions. This means that adopting a specific technology in one region will influence also the adoption in the neighbouring regions. The support for Hypothesis 4 highlights the crucial role of contextual factors in creating an ecosystem conducive to technological advancement and web technology adoption.

Moreover, the study shows how important geographical positioning is for the type of technologies to be adopted. The more integrative technologies such as the Javascript library will have smoother diffusion and will be adopted faster by firms. However, the specialised, isolated technologies (Live Chat technologies) will diffuse more slowly as they require higher adoption capacity and it depends on the industrial specialisation of the regions. So industrial specialisation will eventually drive digital technologies that are adopted. Concluding that the place still matters for digital web technology adoption.

These hypotheses explain the complicated interplay between the place-based factors, the business environment and the dynamics of web technology adoption in EU regions. The findings suggest that the spatial factors and agglomeration characteristics of a region do not just support the development of digital complexity but also play a pivotal role in enabling web technology adoption. Therefore refuting the idea of the death of space. This reinforces the idea that beyond the intrinsic characteristics of web technologies and the cognitive proximity between them, the spatial context and the density or geographical positioning of economic and industrial activities within a region are critical determinants of both digital complexity and the capacity for digital technological innovation and adoption.

Hypothesis H5 *There is a reciprocal positive relationship between digital technology adoption and GDP per capita. This implies that not only does technology adoption contribute to higher GDP per capita, but also that regions with higher GDP per capita are more capable of adopting new technologies.*

As seen in the results, the effects of digital technology adoption on economic indicators, Hypothesis 5 investigates the complex interplay between digital technology adoption and economic growth. As seen in the results while testing Hypothesis 5 there is a reciprocal relation between technology adoption and GDP per capita, however not for all technologies. This indicates a symbiotic ecosystem dynamic where digital technological advancements contribute to economic prosperity, the relationship is significant and positive only for certain technologies (Javascript library and Audience measurement) and negative for others. Therefore I only partially accept the 5 hypothesis. In turn, economic prosperity creates a conducive environment for further web technology adoption for the majority of web technologies. This hypothesis is supported by empirical evidence demonstrating that regions with higher levels of economic prosperity in terms of GDP show a greater probability of adopting new technologies, such as Javascript libraries, likely due to better resources, skilled labour and the infrastructure available. This mutual influence highlights the critical role of economic conditions in shaping technology adoption patterns, highlighting that economic prosperity and technological advancements are mutually reinforcing.

Overall, Hypothesis 5 elucidates the mutual relationship between digital technology adoption and economic outcomes. It highlights the transformative power of technology in reshaping economic landscapes, driving productivity, and propelling regions towards higher levels of economic development. This discussion highlights the importance of fostering an ecosystem that encourages innovation and leverages technological adoption for economic benefit, moreover it emphasises the bidirectional influence between technology and economic prosperity.

Finally it is needed to integrate the insights from Hypotheses 3, 4 and 5 with the broader conceptual frameworks of entrepreneurial ecosystems and smart specialization. Here we can extend the discussion to encapsulate how the study's findings can be integrated with the abovementioned theoretical constructs. The dynamics of web technological innovation, adoption, and regional economic development observed in this dissertation are instrumental in understanding the entrepreneurial ecosystem and smart specialization strategy (S3).

Smart specialization recognises the role of entrepreneurial discovery and the prioritization of innovation domains by specialising on the existent capabilities, advocating for a place-based, bottom-up approach to regional development. The findings of this study align with the S3 strategy relating to the positive impact of contextual factors on digital complexity and technology adoption (Hypotheses 2, 3 and 4). By fostering synergetic environments where entrepreneurs can leverage existing competencies and resources, regions can effectively absorb and capitalize through digital technology adoption on the opportunities presented by digital transformation. Smart specialization aims to reduce discrepancies between core and periphery regions by underlining the importance of place-specific innovation strategies that are ex-ante informed by existing local conditions and entrepreneurial activities. This can be achieved by undertaking a place-based view also on digital technology adoption.

Moreover, the interaction between entrepreneurial ecosystems and smart specialization strategies highlights the necessity of a supportive framework for innovation and economic growth aided by digital technologies (Hypotheses 3, 4 and 5). The entrepreneurial ecosystem, with its focus on the interconnectedness of actors, resources, and institutions, provides a fertile ground for the implementation of smart specialization strategies aided by the adoption of digitally complex and related technologies. This ecosystem fosters the development of competencies and the aggregation of resources necessary for the exploration of new and related digital technological paths, as evidenced by the positive relationship between technology adoption and economic growth for specific technologies.

The study's findings highlight the importance of contextual place-based factors and the reciprocal relationship between technology adoption and GDP per capita. Moreover, the significant impact of technology adoption and density of related technologies on economic growth resonates with the core principles of smart specialization. By identifying and supporting areas of potential growth that are closely related to existing strengths, regions can achieve transformative and sustainable economic development as their new capabilities are related to their old ones. This approach not only leverages the inherent advantages of related technologies and digital complexity but also by digital technology adoption aligns with the entrepreneurial discovery processes where digital technology adoption is transformed into new business models and spin-offs, that are central to the entrepreneurial ecosystem and smart specialization framework.

In summary, this dissertation attempts to integrate entrepreneurial ecosystems and smart specialization strategies with Economic Geography aspects and digitalization. Within the study, I highlight the complex interdependencies between related and complex digital technologies, digital technology adoption, economic growth, and regional innovation policies. All these previously enumerated findings ask for a detailed understanding of regional development, where the synergies between digital technological advancements, economic and business conditions, and policy frameworks with a place-based focus are recognized and improved to foster sustainable growth and digital innovation across European regions.

4.2 Implications for Policy and Practice

The strategic implications of this dissertation for policymakers and stakeholders are significant, particularly when digitalization is viewed through the lenses of space, geography, smart specialization (S3), and entrepreneurial ecosystems. The significance of relatedness density in enhancing digital technology adoption and digital complexity presents a compelling case for the development of interconnected technological ecosystems. These findings highlight the importance of using spatial and geographic advantages in regional development policies to foster environments that support the integration of new technologies. Policymakers are encouraged to recognize the spatial dimensions of digitalization and innovation, ensuring that regional policies capitalize on each region's unique geographic characteristics and existing digital technological capabilities or industrial orientation.

The concept of smart specialization can serve as a key framework for achieving the upper objectives. It advocates for policies that promote innovation and inclusive sustainable growth by focusing on the existent unique regional strengths, capabilities and competitive advantages. Smart Specialisation can take a similar view on digitalization. As its approach aligns with the need to foster environments that leverage existing digital technological capabilities and knowledge networks, enabling regions to effectively integrate new digital technologies and maintain their competitiveness in the digital era. Policymakers should embrace the principles of smart specialization to guide the strategic prioritization and development of regional entrepreneurial ecosystems, emphasizing the importance of entrepreneurial discovery and innovation-driven economic development in digitalization.

Moreover, the digital complexity paradox identified in this study highlights the challenges of digital technology saturation, the complexity of adoption and compatibility issues, necessitating a balanced approach to digital advancement. By following the smart specialization strategy, policymakers should focus on optimizing existing technological infrastructures while carefully integrating new digital innovations. This requires considering attention to understanding digital complexity's role in technology adoption, emphasizing the need for policies that support sustainable technological advancement and economic growth within the context of each region's unique spatial and geographic characteristics.

By integrating the concepts of smart specialization, entrepreneurial ecosystems and digital technology adoption into regional development strategies, policymakers can create a supportive environment for innovation and further technology adoption or new business models. This environment will encourage collaboration among stakeholders, leverage the region's unique spatial and geographic advantages, and focus on building and strengthening the interconnected digital-physical technological ecosystems that are crucial for the digital era. Thus, crafting policies that reflect an understanding of the spatial dynamics of innovation, the principles of smart specialization, and the importance of entrepreneurial ecosystems becomes essential for fostering technology adoption, digitalization and overall regional economic growth.

4.3 Directions for Future Research

This dissertation can serve as the cornerstone for numerous directions of future research. One critical area that requires attention involves understanding the mechanisms through which regional digital complexity might negatively impact technology adoption but also productivity. Moreover, future studies should explore the effects of market saturation of digital technology, compatibility issues, and the incremental costs associated with the adoption of new digital web technologies, especially in regions with advanced digital ecosystems. In this study we focused more more of the impact of related technologies and, therefore on incremental innovations, a deeper focus on unrelated web technologies is required. Additionally, there is a need for comparative studies across different geographic contexts to unravel the spatial dynamics of technology adoption and digital complexity.

While this empirical study attempted to examine the place-specific factors, more attention should be paid to digital infrastructure and digital adoption capacities, as few digitalization controls were considered. Such research could elucidate our understanding of how different regions navigate the challenges and opportunities of digital transformation. To diminish the gap between developed and underdeveloped regions, policy interventions are necessary, and this dissertation offers valuable insights for both policymakers and practitioners, but more specific case studies are needed.

4.4 Conclusion

In conclusion, this dissertation has illuminated the intertwined relationships between relatedness density, digital complexity, and technology adoption across European regions. By exploring these dynamics, the study contributes to a deeper understanding of the factors that drive digital technological evolution and regional development. The findings underscore the importance of fostering interconnected innovation and entrepreneurial ecosystems and adopting a direct and clear approach to digital complexity. As we move forward, it is imperative that policymakers and stakeholders heed these insights, leveraging them to foster environments that support innovation, economic growth, and technological advancement. This study designed a framework and identified specific factors influencing digital technology adoption. Future research in this domain holds the potential to further refine our understanding of these complex dynamics, offering guidance for navigating the challenges of the digital era.

This comprehensive exploration not only advances the academic discourse on digital transformation but also provides actionable recommendations for policymakers and practitioners aiming to harness the benefits of digital technological advancements for regional development.

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