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Digital Divide and Innovation in European Enterprises: A Multi-Method Analysis of Firm and Sectoral Dynamics

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Digital Divide and Innovation in European Enterprises: A Multi-Method Analysis of Firm and Sectoral Dynamics

Abstract: This cumulative dissertation examines the digital divide among enterprises, an underexplored dimension of digitalisation research that extends beyond simple asymmetries in technology diffusion and adoption to reveal deeper organisational inequalities. It comprises four interconnected chapters. Chapter 1 introduces the research problem, outlining its motivation, conceptual underpinnings, and methodological approach, and concludes by highlighting the study's contributions, limitations, and avenues for further inquiry. Chapter 2 conducts a bibliometric analysis of European scholarship on the digital divide, revealing the persistent underrepresentation of firm-level perspectives. Chapter 3 develops the Resources and Technology Integration Framework (RTIF), an adaptation of van Dijk's Resources and Appropriation Theory, to capture the organisational dynamics of access, skills, and usage of digital technologies. Chapter 4 applies this framework empirically to Italian enterprises using ICT usage survey data and factor analysis to assess disparities in access, skills, and usage. The findings indicate that while policy measures have significantly reduced access gaps, inequalities in digital skills and technology usage remain particularly pronounced among SMEs and in southern regions. Collectively, the chapters provide conceptual, methodological, and empirical insights that advance the understanding of organisational digital inequalities and offer evidence to inform more inclusive and targeted digital transformation policies.

Keywords: Digital divide; Enterprises; Access, skills and usage; Organisational inequalities; Factor analysis.

Divario Digitale e Innovazione nelle Imprese Europee: Un'Analisi Multi-Metodo delle Dinamiche Aziendali e Settoriali

Riassunto: Questa tesi cumulativa esamina il divario digitale tra le imprese, una dimensione poco esplorata nella ricerca sulla digitalizzazione che va oltre le semplici asimmetrie nella diffusione e nell'adozione delle tecnologie per rivelare disuguaglianze organizzative più profonde. La tesi si articola in quattro capitoli interconnessi. Il Capitolo 1 introduce il problema di ricerca, ne illustra la motivazione, i fondamenti concettuali e l'approccio metodologico, e si conclude evidenziando i contributi, i limiti e le prospettive future di ricerca. Il Capitolo 2 presenta un'analisi bibliometrica della letteratura europea sul divario digitale, mettendo in luce la persistente sotto-rappresentazione delle prospettive a livello d'impresa. Il Capitolo 3 sviluppa il *Resources and Technology Integration Framework* (RTIF), un adattamento della *Resources and Appropriation Theory* di van Dijk, per analizzare le dinamiche organizzative legate all'accesso, alle competenze e all'uso delle tecnologie digitali. Il Capitolo 4 applica empiricamente questo quadro teorico alle imprese italiane utilizzando i dati delle indagini sull'uso delle ICT e l'analisi fattoriale per valutare le disparità in termini di accesso, competenze e utilizzo. I risultati mostrano che, sebbene le politiche pubbliche abbiano contribuito a ridurre i divari di accesso, le disuguaglianze relative alle competenze digitali e all'uso delle tecnologie permangono, in particolare tra le PMI e nelle regioni meridionali. Nel complesso, i capitoli offrono contributi concettuali, metodologici ed empirici che avanzano la comprensione delle disuguaglianze digitali a livello organizzativo e forniscono evidenze utili per politiche di trasformazione digitale più inclusive e mirate.

Parole chiave: Divario digitale; Imprese; Accesso, competenze e utilizzo; Disuguaglianze organizzative; Analisi fattoriale.

Digitale Kluft und Innovation in Europäischen Unternehmen: Eine Multimethodenanalyse der Unternehmens- und Sektorendynamiken

Zusammenfassung: Diese kumulative Dissertation untersucht die digitale Kluft zwischen Unternehmen, einen bislang wenig erforschten Aspekt der Digitalisierungsforschung, der über reine Asymmetrien in der Verbreitung und Einführung digitaler Technologien hinausgeht und tiefgreifende organisationale Ungleichheiten offenlegt. Die Arbeit besteht aus vier miteinander verknüpften Kapiteln. Kapitel 1 stellt das Forschungsproblem vor, erläutert die Motivation und den methodischen Ansatz und schließt mit den zentralen Beiträgen der Arbeit sowie Perspektiven für zukünftige Forschung. Kapitel 2 bietet eine bibliometrische Analyse der europäischen Literatur zur digitalen Kluft und zeigt die geringe Berücksichtigung von Unternehmen in diesem Forschungsfeld auf. Kapitel 3 entwickelt das *Resources and Technology Integration Framework* (RTIF), eine Adaption von van Dijks Theorie der Ressourcen und Aneignung für organisatorische Kontexte. Kapitel 4 wendet dieses theoretische Modell empirisch auf italienische Unternehmen an und analysiert mithilfe von ICT-Umfragedaten Unterschiede beim Zugang zu digitalen Technologien, bei digitalen Kompetenzen und bei der Nutzung. Die Ergebnisse zeigen, dass politische Maßnahmen zwar zur Verringerung von Zugangsbarrieren beigetragen haben, jedoch weiterhin deutliche Ungleichheiten in Bezug auf Kompetenzen und Nutzung bestehen, insbesondere bei KMU und in den südlichen Regionen. Zusammengenommen liefern die Kapitel konzeptionelle und empirische Erkenntnisse, die zur Entwicklung inklusiverer und gezielterer digitalpolitischer Strategien beitragen können.

Schlüsselwörter: Digitale Kluft; Unternehmen; Zugang, Kompetenzen und Nutzung; Organisationale Ungleichheiten; Faktorenanalyse.

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Chapter 1 - Uncovering the Organisational Digital Divide: Motivations, Gaps, and a Framework for Cumulative Inquiry

Abstract: The digital divide is often seen as a social issue, focusing on access and literacy for individuals. However, digital disparities also exist among businesses, and uneven digital adoption can deepen economic inequalities across sectors, regions, and company sizes. Chapter 1 sets the stage for a cumulative dissertation that addresses this overlooked area by reframing the digital divide as a firm-level phenomenon. It argues that digital transformation is not uniformly beneficial and that enterprises lacking foundational digital capabilities may fall behind, not simply due to internal inertia but because of systemic constraints in institutional, technological, and organisational environments. The chapter identifies a research gap at the crossroads of innovation economics, digital policy, and organisational studies. It argues that digital transformation strategies often assume all firms can equally adopt digital tools, overlooking persistent inequalities in infrastructure, skills, and practices. The digital divide is viewed as a dynamic, multifaceted process shaped by resources, incentives, and market forces. To explore this process, the chapter formulates a set of overarching research questions that frame the inquiry into how digital inequalities manifest across firms, and how differences in access, skills, and usage interact across sectors, firm sizes, and institutional contexts. These overarching questions guide the cumulative design of the dissertation. At the same time, each chapter further refines them to suit its specific objectives, ranging from literature mapping to theoretical elaboration and empirical validation. Finally, the chapter outlines the structure of the dissertation. It presents Chapter 2 as a bibliometric mapping of the literature, Chapter 3 as a theoretical contribution, and Chapter 4 as an empirical application using firm-level data from Italy.

Keywords: digital divide, firms, literature review, theoretical framework, factor analysis.

JEL Classification: D83, O33, O52

1.1. Introduction

Technology has long been a fundamental driver of economic and societal transformation, influencing industries, labour markets, and geopolitical structures (Mokyr, 1990). Traditionally, technological advancements have been classified into broad categories, including mechanical, chemical, biological, and digital innovations, each shaping production processes and economic systems in distinct ways (Perez, 2003). However, within this broad spectrum, digital technologies stand apart due to their distinctive reliance on computational power, their ability to process and distribute information, and their potential to reshape production, consumption, and decision-making in real-time (Brynjolfsson & McAfee, 2014). Digital innovations, unlike traditional technologies, generate value through data manipulation and network effects, allowing for rapid scalability and widespread applicability across sectors (Schüler & Petrik, 2023). In contrast to traditional technologies that often function within specific sectors, digital technologies are cross-sectoral and exhibit exponential growth patterns, fundamentally altering the structure of firms, industries, and global economies (Steen et al., 2022).

One defining characteristic of digital technologies is their classification as General Purpose Technologies (GPTs), a concept described by Bresnahan and Trajtenberg (1995) as technologies that enable continuous and widespread innovation across multiple industries. Examples include the steam engine, electricity, and the internet. Digital technologies like the internet, AI, cloud computing, data analytics, and blockchain exhibit GPT characteristics by transforming economic structures and driving innovation in industries such as manufacturing, finance, healthcare, and education. (Cockburn et al., 2018). Their cross-sectoral impact allows for productivity gains and efficiency improvements, yet their adoption and benefits remain unevenly distributed across firms, sectors, and regions (Billon et al., 2017; Shakina et al., 2021; Jan. van Dijk, 2006). This cross-sectoral impact means that digital technologies do not merely enhance efficiency within existing business models; they fundamentally reshape how economic value is created, how firms compete, and how industries evolve over time (Liu, 2022).

Digital technologies play a prevalent role and are far from neutral tools that businesses can merely adopt or disregard. Their implementation is influenced by various constraints and opportunities, including institutional policies, geopolitical rivalries, labour frameworks, and global supply networks (Crawford, 2022; Øverby & Audestad, 2021). Contrary to traditional economic models that presume technological spread happens organically, empirical findings indicate that digitalisation is notably uneven, benefiting those firms, industries, and regions that possess the right infrastructure, expertise, and financial access (Billon et al., 2017; Cirera et al., 2022). This reality calls for an in-depth exploration of digital technologies, distinguishing them from general technological advancements, as their diffusion and impact are shaped by distinct political, economic, and institutional configurations (Labhard & Lehtimäki, 2022; Nicoletti et al., 2020). In this broader transformation, the digital economy has emerged as a dominant paradigm in which economic activities are increasingly structured around digital platforms, data-centric business models, and algorithmic governance (Lehdonvirta, 2013; Zuboff, 2019). Unlike traditional industrial economies focused on tangible outputs and manufacturing processes, the digital economy revolves around the generation, extraction, and monetisation of data, with powerful technology firms playing a central role in shaping market structures, influencing user behaviour, and redefining value creation (Conyon et al., 2022; Goldfarb & Tucker, 2019).

Taking this into consideration, this chapter offers a conceptual and analytical foundation for understanding digital inequalities among enterprises. It develops the argument that digital transformation is not a neutral or uniform process, but one shaped by historical, institutional, and economic asymmetries. Following this introductory first section, Section 1.2 conceptualises digital technologies and the digital divide, challenging traditional interpretations and proposing a political economy perspective. Section 1.3 explores major economic theories, ranging from neoclassical to institutional economics, to examine how different schools of thought explain the creation, access, and diffusion of technology. Section 1.4 discusses the dual nature of digital technologies, highlighting their potential to drive economic development while also reproducing inequality and regulatory complexity. Building on this, Section 1.5 outlines the rationale for a research agenda focused on firm-level digital disparities, proposing a set of overarching research questions and introducing the Resource and Technology Integration Framework (RTIF). Section 1.6 provides an overview of the subsequent chapters, while Section 1.7 reflects on the contributions and future research directions. Together, these sections position the chapter as both a foundation for and a gateway into a cumulative inquiry into the organisational digital divide.

1.2. Conceptualising Digital Technologies and the Digital Divide

Digital technologies encompass a broad set of electronic tools, systems, and platforms that enable the generation, storage, processing, and exchange of information through computational and communication infrastructures (Berger et al., 2018; OECD, 2019). These technologies include computing infrastructures (e.g., processors, cloud computing, high-speed internet), communication systems (e.g., 5G, satellite networks), data-centric tools (e.g., artificial intelligence, big data analytics, IoT), and automation systems (e.g., robotics, machine learning applications). Unlike traditional industrial technologies, which are often confined to specific production sectors, digital technologies exhibit cross-sectoral scalability, interoperability, and a recursive learning dynamic through data-driven feedback mechanisms (Barredo Arrieta et al., 2020; Tambe, 2014).

Their distinctive characteristics can be better understood through what Baldwin (2019) conceptualises as the "four laws" of digital technology. First, Moore's Law posits that computing power doubles approximately every 18 months, fuelling exponential processing capabilities. Second, Gilder's Law highlights the even faster expansion of data transmission capabilities, tripling relative to processing growth, thereby enabling real-time, global digital communication. Third, Metcalfe's Law explains that the utility of digital networks increases with the square of the number of connected users, producing powerful network effects that amplify technological value. Finally, Varian's Law suggests that once digital building blocks such as code, protocols, or datasets are created, they can be replicated and recombined at near-zero cost. Paradoxically, while these components are often free, the digital products made from them can be extremely valuable, fuelling a surge of innovation through open access and combinatorial creativity (Baldwin, 2019).

Taken together, these laws help explain why digital technologies are not only pervasive but also cumulative and disruptive, intensifying structural divides in access, capability, and meaningful use across firms. Their increasing strategic importance lies not simply in their efficiency-enhancing potential but in their ability to reshape competition, redefine firm capabilities, and shift control over the means of information production and distribution (Acemoglu & Restrepo, 2020; Brynjolfsson & McAfee, 2014).

1.2.1. Beyond the Traditional Digital Divide: A Political Economy Perspective

The conventional understanding of the digital divide has historically focused on first-level disparities, the gap between those who have access to digital infrastructure and those who do not (Norris, 2001; Jan. van Dijk & Hacker, 2003). This binary framework assumes that bridging the access divide (e.g., expanding broadband coverage or providing computers) is sufficient to ensure equitable participation in the digital economy. In the early 2000s, scholarship broadened this definition to encompass second and third-level digital divides. These include gaps in digital skills, technology usage (Hargittai, 2002), and the economic advantages gained from technology (Helsper et al., 2015; Ragnedda, 2017). Even with access barriers eliminated, businesses and individuals still face structural inequalities in their capacity to integrate, utilise, and benefit from digitalisation.

In the diffusion and innovation literature, differences in adoption are often described as asymmetries or as cases of incomplete diffusion, with an emphasis on the speed and breadth of technological uptake across firms and regions. The digital divide literature, however, interprets these same differences as structural inequalities that can be analysed through the dimensions of access, skills and usage. In this dissertation, the use of the term "*asymmetries*" does not suggest a distinction from the digital divide, but connects the two traditions. Adoption asymmetries are the observable results of unequal diffusion. At the same time, the digital divide framework highlights the structural conditions, including resources, institutions, organisational capacities, and market dynamics, that generate and perpetuate these asymmetries. In this sense, the RTIF bridges the gap between diffusion studies, which focus on outcomes, and digital divide research, which focuses on the underlying mechanisms.

Beyond individual and firm-level adoption, digital disparities are increasingly influenced by global political and economic forces. The geopolitical struggle for digital dominance, exemplified by the U.S.-China technology rivalry, illustrates that digitalisation is not just about technological access but also about strategic control (Lundvall & Rikap, 2022; Miller, 2022). The United States dominates the AI and software sectors, leveraging intellectual property regimes, venture capital networks, and proprietary algorithms to establish digital hegemony (Chander, 2013; Lee, 2018). In contrast, China has adopted a state-driven approach to digital development, advancing semiconductor manufacturing, AI ecosystems, and 5G infrastructure under initiatives such as Made in China 2025 and the Digital Silk Road (Cheng & Zeng, 2024; Kania, 2021; Zhang et al., 2021). These national strategies have significant implications for global firms, as access to digital tools, cloud computing infrastructure, and AI capabilities is increasingly shaped by geopolitical alignments, sanctions regimes, and digital sovereignty[1] policy factors that go beyond conventional market considerations (Pohle et al., 2024).

The digital economy also relies on a highly stratified and geographically dispersed global value chain that extends well beyond software development and algorithmic innovation. Digital technologies are profoundly material, depending on the extraction of rare earth minerals, the fabrication of semiconductors, the operation of energy-intensive data centres, and the deployment of human labour for tasks such as AI training and content moderation (Crawford, 2022). For instance, the semiconductor supply chain is heavily concentrated in regions such as Taiwan, South Korea, and mainland China, rendering it a critical site of geopolitical tension and strategic vulnerability (Miller, 2022). Moreover, the development of artificial intelligence is not solely computational; it often requires extensive human input, frequently outsourced to low-wage workers in the Global South who perform data annotation, labelling, and moderation services essential for training machine learning systems (Crawford, 2022; Lee, 2018). These dynamics underscore that the digital divide extends beyond questions of access and usage; it also encompasses the asymmetrical control over the infrastructures, resources, and labour that sustain the digital economy (Acemoglu & Johnson, 2023).

1.2.2. Digitalisation as an Embedded Process, Not Just a Technological Shift

Understanding digital inequalities requires moving beyond the simplistic assumption that digitalisation is an inevitable or neutral process. Firms do not integrate digital technologies in a vacuum; they do so within pre-existing institutional, economic, and geopolitical structures. Some firms operate in economies where digital infrastructure is abundant, and state incentives promote rapid digitalisation, while others struggle in contexts where basic connectivity remains a challenge (OECD, 2024). Similarly, the dominance of major digital giants, such as Google, Microsoft, Meta, Amazon, and Alibaba, creates a landscape where many smaller firms experience a decline in their technological independence, as they become increasingly dependent on proprietary cloud services, AI models, and digital infrastructures managed by these external entities.

[1] The Huawei caseparticularly its exclusion from 5G infrastructure development in the U.S. and several EU countries has become emblematic of digital sovereignty debates. These decisions were justified on the grounds of national security, cybersecurity vulnerabilities, and the strategic control of digital infrastructure (Bu, 2024).

This thesis argues that digital disparities must be understood as the result of both internal firm-level factors and external structural forces that shape digital technology adoption globally. While firms make choices about digital integration, these choices are embedded in a broader system of constraints and opportunities. The framework developed in this research, RTIF, captures these dynamics, accounting for both firm-specific capabilities and the role of institutions, market structures, and technological change in shaping digital access, skills, and usage. As discussed in Chapter 3, external constraints, including regulatory policies, platform dependencies, and digital infrastructure disparities, play a crucial role in determining how firms integrate and utilise digital tools.

By examining these three dimensions, this research moves beyond conventional digital divide analyses and situates digitalisation within the broader political economy of technological change. In doing so, it provides a framework to assess how digital disparities are not just a matter of who adopts technology but how, under what constraints, and to what end.

1.3. Economic Interpretations of Technology Creation, Access, and Diffusion

Technology adoption has long been a central topic in economic theory, with different schools of thought offering varying explanations for how technology is created, accessed, and distributed. This section presents six major economic perspectives: neoclassical growth theory, endogenous growth theory, knowledge economy, evolutionary economics, Schumpeterian creative destruction, and institutional economics, each of which conceptualises technology in distinct ways before applying these insights to digital technologies.

1.3.1. Neoclassical Growth Theory

Neoclassical growth models, particularly those developed by Solow (1956), treat technology as an exogenous factor that enhances productivity and is freely accessible across the economy. These models assume that firms and individuals adopt technology as soon as it becomes available, leading to uniform technological progress. Since technology is conceptualised as a public good, disparities in adoption are regarded as temporary market inefficiencies rather than structural barriers (Torrent-Sellens, 2024). However, empirical research challenges this assumption, demonstrating that access to technology is often restricted by factors such as financial constraints, intellectual property protections, and variations in human capital (Brynjolfsson & Hitt, 2003; Cirera et al., 2022).

1.3.2. Endogenous Growth Theory

Endogenous growth models, introduced by Romer (1990) and Lucas (1988), counter the neoclassical assumption by positing that technology results from deliberate investments in research and development (R&D), human capital, and innovation ecosystems. Unlike the assumption of universal access, these models highlight that access to technology is uneven and shaped by factors such as intellectual property rights, R&D capabilities, and absorptive capacity (Cohen & Levinthal, 1990; Maskus, 2000; Pavitt, 1984). Technology diffusion, in this view, is neither automatic nor universal but contingent on the ability of firms and regions to invest in and integrate new knowledge (Arrow, 1962; Nelson, 1993).

1.3.3. Knowledge Economy

The knowledge economy framework views technology as a knowledge-embedded asset created through cumulative learning, organisational capabilities, and collaborative innovation rather than as a standalone input or automatic outcome of R&D. Within this perspective, access to technology is contingent upon firms' absorptive capacity, human capital, and their embeddedness in knowledge-intensive networks, such as regional innovation systems and global value chains (Cohen & Levinthal, 1990; Cooke, 2001; David & Foray, 2003; Lundvall & Lorenz, 2012). Unlike endogenous growth theory, which emphasises formal investment in innovation, the knowledge economy underscores the role of tacit knowledge and institutional linkages in shaping firms' digital capabilities. Diffusion is relational and path-dependent, occurring unevenly across firms and regions based on their ability to participate in dense knowledge ecosystems. As such, digital disparities reflect not only investment gaps but also structural inequalities in how firms acquire, apply, and benefit from knowledge-based resources.

1.3.4. Evolutionary Economics

Evolutionary economics, pioneered by Nelson and Winter (1985), rejects the notion that firms instantaneously adopt optimal technologies. Instead, technological change is viewed as a path-dependent process influenced by historical investments, organisational routines, and industry norms. Firms that have previously invested in certain technological infrastructures may find it difficult to transition to newer, more efficient alternatives due to sunk costs and technological lock-in (Cantner & Vannuccini, 2016). This framework explains why some firms and regions consistently lead in technological adoption while others remain technologically stagnant (Fritsch & Slavtchev, 2011).

1.3.5. Schumpeterian Economics

Schumpeter (1942) introduced the concept of creative destruction, arguing that technological innovation disrupts existing industries, creating winners and losers. This perspective challenges the notion that technology benefits all economic agents equally, instead highlighting how technological advancements lead to market concentration, monopolisation, and industry displacement (Aghion & Howitt, 1992). The disruptive nature of innovation, particularly in fast-changing industries, exacerbates economic disparities, as firms that fail to adapt are left behind, unable to compete with technologically dominant incumbents (Hanusch & Pyka, 2007; Levinthal, 1998).

1.3.6. Institutional Economics

Institutional economics (North, 1990) emphasises that technology diffusion is significantly affected by the quality of institutions, regulatory frameworks, and governance rather than being driven solely by market forces. Elements such as intellectual property laws, competition policies, and public funding for R&D influence whether technologies are widely adopted or remain confined to a small group of firms. Furthering this viewpoint, Acemoglu and Robinson (2013) contend that inclusive institutions, which facilitate broad access to education, finance, and innovation, promote extensive technological adoption. In contrast, extractive institutions, which centralise power and limit resource access, inhibit diffusion and exacerbate inequality. Therefore, institutional structures not only affect innovation outcomes but also the distribution of technological capabilities among firms and regions. According to Acemoglu and Johnson (2023), the path of innovation is not predetermined; it is shaped by the political and institutional factors that govern technology, determine which issues are prioritised, and decide whose welfare the innovation ultimately serves. Therefore, institutional structures influence not only the adoption of technology but also its purpose and the subsequent effects on distribution.

1.3.7. Synthesising Economic Theories for Digital Disparities

The economic perspectives discussed above provide a valuable foundation for understanding digital inequalities. While neoclassical models assume that technology spreads evenly, empirical evidence on digitalisation reveals a more complex reality: digital technologies do not diffuse automatically but are shaped by investment disparities, institutional conditions, and structural asymmetries (Berlingieri et al., 2020).

Endogenous growth theory highlights how innovation outcomes concentrate in high-R&D regions and firms with strong human capital, reinforcing technological divides. Complementing this, the knowledge economy perspective explains that technology adoption also depends on firms' ability to absorb and apply knowledge, which in turn is shaped by their position within learning ecosystems, access to tacit knowledge, and organisational capabilities. In this view, digital disparities reflect not only uneven investment but exclusion from networks where knowledge circulates and accumulates.

Evolutionary economics adds that historical trajectories and technological lock-ins constrain firms' capacity to adapt, creating path dependencies in digital transformation. Schumpeterian dynamics show how digital innovation often leads to monopolistic control over infrastructures and standards, further marginalising less advanced firms. Finally, institutional economics underscores how governance, policy incentives, regulatory regimes, and institutional spheres of influence shape access to digital tools, conditioning both the pace and direction of adoption. Taken together, these perspectives show that digital inequalities stem from systemic and multi-layered factors, economic, institutional, and organisational, that shape how technologies are produced, accessed, and diffused across firms and regions.[2]

1.4. The Dual Role of Digital Technologies

Digital technologies have emerged as a central force in the reconfiguration of economic systems, offering new possibilities for value creation, organisational efficiency, and interconnectivity. Yet, their impact is far from uniform or universally beneficial. As Acemoglu and Johnson (2023) emphasise, the trajectory of technological progress is not solely determined by technical capabilities but by the institutional, political and power structures that guide its development. This dual nature means that while digital tools can enhance productivity and innovation, they can also reinforce existing inequalities if the underlying institutional configurations are extractive rather than inclusive (Acemoglu & Robinson, 2012). Moreover, digitalisation often advances within entrenched power dynamics, privileging firms and regions with the necessary digital infrastructure, absorptive capacity, and human capital. Thus, digital

[2] This synthesis draws on insights from Romer (1990), Lucas (1988), Aghion and Howitt (1992), David and Foray (2003), Lundvall (2012), Cohen and Levinthal (1990), Nelson and Winter (1985), Schumpeter (1942), Acemoglu and Robinson (2013), Acemoglu & Johnson (2023), Baldwin (2019).

technologies should be understood not merely as tools of economic progress but also as mechanisms that can amplify structural disparities across and within enterprises.

1.4.1. Digital Technologies as Drivers of Economic Expansion

When strategically aligned with organisational capabilities and embedded in robust innovation ecosystems, digital technologies can yield considerable economic benefits. Research suggests that their deployment enhances operational efficiency, facilitates global integration, and accelerates decision-making processes (Bharadwaj et al., 2013; Matt et al., 2015). In regions with strong institutional support and highly skilled labour markets, digital transformation has been associated with increased investment in research and development (R&D), improved productivity, and the emergence of new business models (Li et al., 2023). Moreover, frontier digital technologies such as big data analytics, 3D printing, and robotics have shown potential to support innovation under specific conditions, particularly when they complement internal or external R&D efforts (Usai et al., 2021). The generative and modular nature of these technologies offers pathways for firms to engage in both incremental and radical innovation (Baldwin & Clark, 2000; Yoo et al., 2012), making them essential components of digital-era competitiveness. Yet these benefits are not universally realised, and digitalisation also presents new threats to social and economic equity.

1.4.2. Risks and Uneven Outcomes of Digital Transformation

Despite their promise, digital technologies can also produce unintended consequences and deepen socio-economic inequalities. Evidence from European firms suggests that, contrary to common assumptions, digital technologies on their own have a limited impact on innovation performance, particularly when not accompanied by deliberate R&D strategies and human capital investment (Usai et al., 2021). At the intra-firm level, digital transformation may reduce wage gaps between managerial and general staff, but often does so while widening disparities between high-skilled and low-skilled employees (Li et al., 2023). Moreover, overreliance on standardised digital solutions may deplete relational capital and creative capabilities, reducing a firm's ability to generate unique, inimitable knowledge (Usai et al., 2021). These insights are echoed by recent research showing that corporate digitalisation can either reduce or amplify operational risk, depending on a firm's size, governance capacity, and the quality of local digital infrastructure (Jiang et al., 2025). While digital tools may enhance internal control and performance in well-positioned firms, overinvestment or misaligned implementation strategies may strain resources and increase volatility, particularly in firms with limited absorptive capacity. These findings underscore that without adequate institutional support, such as equitable education systems, inclusive innovation policies, and labour protections, digital technologies risk reinforcing existing divides. As such, the benefits of digital transformation cannot be presumed; they must be actively governed and directed towards inclusive and sustainable outcomes (Acemoglu & Johnson, 2023).

These dynamics are further illustrated in recent empirical analyses. As shown in Figure 1, the distribution of digital maturity remains highly uneven across sectors and regions. In the European Union, a substantial share of firms in both manufacturing and services remain in the "beginner" or "non-digital" categories, while in the United States, a greater proportion of firms have transitioned into "frontrunner" or "catching-up" status (Rückert et al., 2020).

While these disparities highlight one side of digitalisation, the technologies themselves also offer substantial economic potential under the right conditions.

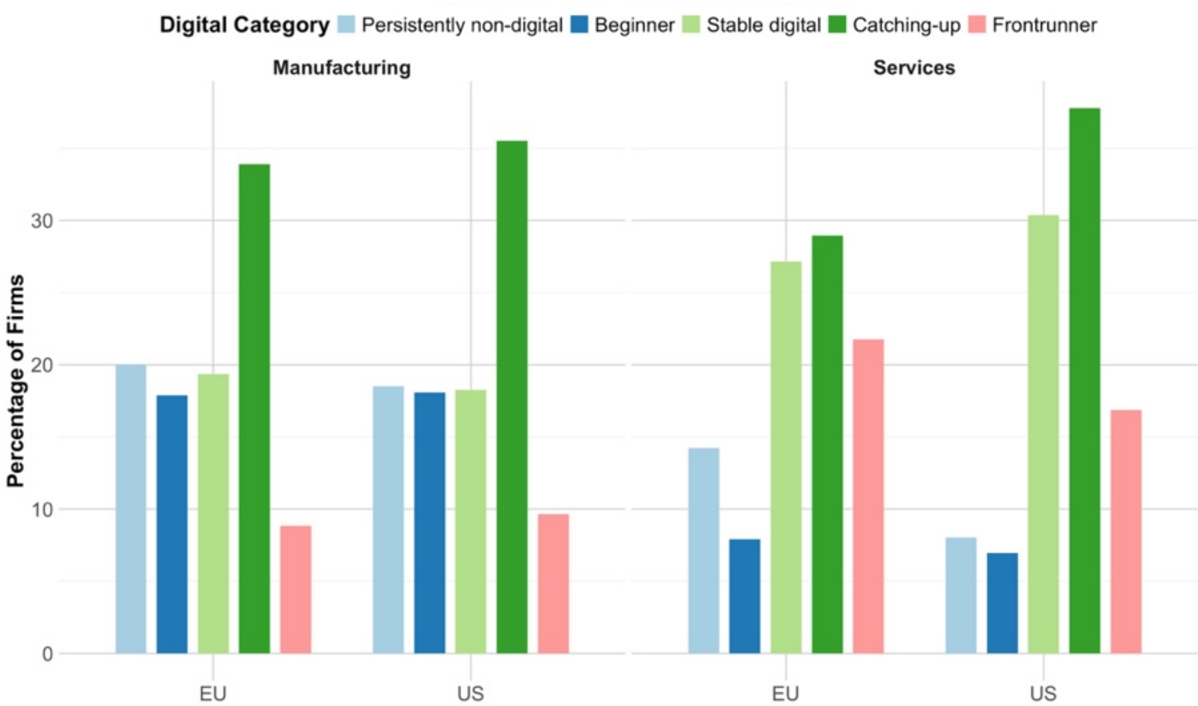

Figure 1: Digital divide by sector and region in 2018: Share of firms by digital maturity level in the EU and US across manufacturing and services.

Source: Adapted from Rückert et al., (2020)

1.4.3. Market Concentration and the Digital Economy

The digital economy is increasingly characterised by a significant concentration of market power, where a small number of dominant technology firms exert substantial influence across core sectors such as artificial intelligence, cloud computing, and digital marketplaces. These firms leverage strong network effects where the value of a service grows as its user base expands to entrench their positions and extend control across adjacent markets (Srnicek, 2017; Zuboff, 2019). As a result, entry barriers for smaller or late-adopting enterprises become challenging. This oligopolistic behaviour of the market raises serious concerns for competition, as it may stifle entrepreneurial experimentation, reduce consumer choice, and concentrate technological capabilities in the hands of a few global actors. Moreover, this concentration creates challenges for regulatory authorities, which frequently lack the flexibility or the institutional tools needed to tackle market tipping, cross-market dominance, and exclusion driven by data. In this case, digital transformation might not promote economic democratisation; rather, it could strengthen existing structures, expanding the divide between leading digital firms and those lagging in technological advancement.

Figure 2 illustrates how the period from 2014 to 2023 saw a significant shift in global corporate leadership, with technology-intensive firms such as Apple, Alphabet, Microsoft, Meta, and NVIDIA surpassing traditional industrial leaders in turnover per employee. This shift reflects the unique scalability of data-driven and software-based business models, enabling a disproportionate capture of economic value. While some scholars, like Varian (2019), argue that such outcomes are primarily the result of superior productivity and learning-by-doing, others challenge this view, pointing to strategic behaviours such as serial acquisitions, ecosystem lock-in, and regulatory arbitrage as mechanisms of structural entrenchment (Kanter, 2023; Øverby & Audestad, 2021).

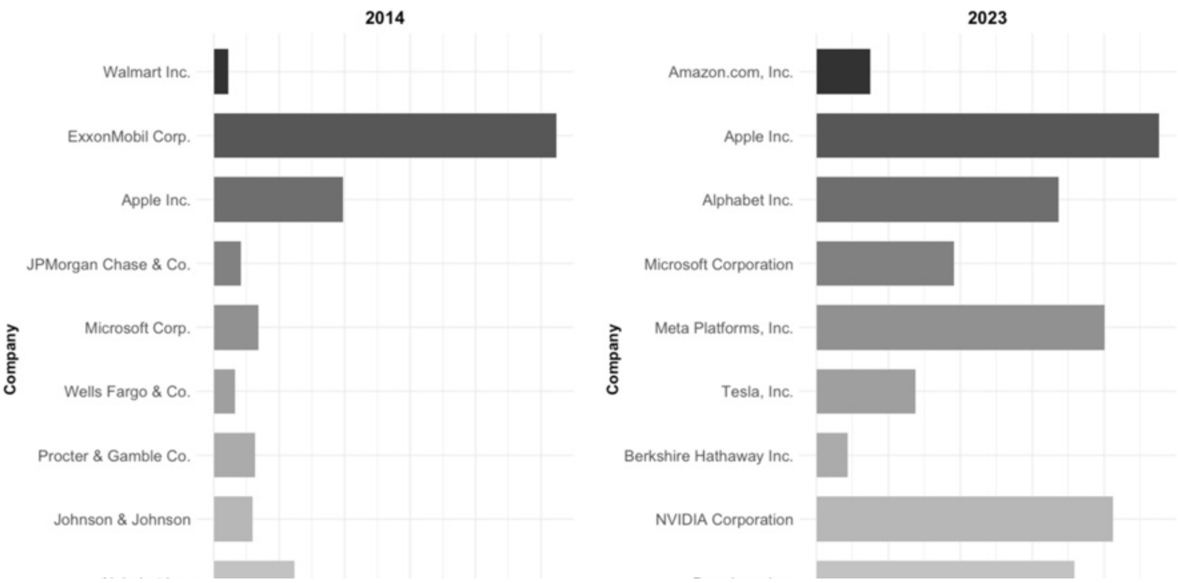

Figure 2: Compares turnover per employee across leading firms in 2014 and 2023. Companies are ordered by market capitalisation within each year.

Source: Orbis Database.

The OECD (2022) similarly cautions that traditional antitrust indicators often understate the depth of market power in digital ecosystems, where influence may manifest not in price but in control over platform access, user data, and innovation pathways. These dynamics suggest that digital transformation, while offering productivity gains, also demands critical scrutiny for its role in reinforcing global economic concentration and institutional asymmetries.

1.4.4. Regulatory and Ethical Challenges

While much of the discussion on the digital divide focuses on disparities in access, skills, and usage, the governance and ethical dimensions of enterprise digitalisation deserve closer attention. As firms adopt increasingly complex digital systems ranging from algorithmic decision-making to data-intensive automation, new challenges emerge around transparency, accountability, and ethical oversight (Floridi, 2018; Mittelstadt et al., 2016). Digitally advanced firms may develop internal protocols to manage algorithmic bias, data governance, and supplier risks, while others, particularly small and medium enterprises (SME), may deploy off-the-shelf solutions without fully understanding their operational or ethical implications. This introduces a layered "governance divide" within the broader digital divide: only some firms have the organisational capacity to evaluate, audit, or adapt digital systems responsibly. Consequently, digital technologies have the potential to replicate or exacerbate structural inequalities (Ragnedda, 2017; Jan. van Dijk, 2006), impacting not only productivity results but also the ethical standards of decision-making and the allocation of accountability (Alegria & Yeh, 2023; Zuboff, 2019). The rapid increase in the use of opaque technologies brings forth a considerable danger of strengthening what can be described as a post-ethical state. In such a scenario, the processes involved in decision-making are predominantly handled through automation, resulting in a situation where ethical considerations are diminished and relegated to simple procedural checklists. This shift raises concerns about the challenges of maintaining moral integrity and accountability in an increasingly automated landscape (Eubanks, 2018). Recognising this dimension helps reframe the digital divide not only as a matter of technical disparity, but also as an institutional and normative gap in how firms navigate digital transformation.

In summary, digital technologies play a fundamentally dual role in the current economic transformation. On one hand, they serve as drivers of organisational efficiency, innovation, and growth; on the other, they reinforce pre-existing disparities, introduce new forms of inequality in access and usage, and concentrate economic value in the hands of a few dominant firms. This duality, fostering expansion while reproducing structural inequalities, is evident not only in adoption patterns across enterprises but also in market power configurations, ethical tensions linked to data and algorithmic decision-making, and the growing need for adaptive and effective regulatory frameworks. These dynamics raise critical questions about how the benefits of digitalisation are distributed, who is positioned to appropriate them, and which institutional conditions enable or hinder a more inclusive digital transformation. Building on these tensions, the next section introduces the research questions that guide this dissertation, focusing on how digital disparities among firms are structured, how they can be measured, and their implications for productive development and competitive dynamics in digitally evolving economies.

1.5. From Digital Policy to Research Questions

Recognising the strategic importance of digital transformation, the European Union (EU) has launched ambitious policy initiatives, such as the Digital Europe Programme, aimed at enhancing Europe's digital competitiveness and fostering technological innovation. This programme, along with other digital policy interventions, seeks to accelerate the deployment of advanced technologies, improve digital skills, and develop high-performance digital infrastructure across households, businesses, and government institutions (Ruohonen & Timmers, 2025). However, as illustrated in Figure 1, significant questions remain regarding the factors that drive persistent digital disparities across sectors, regions, and particularly among firms.

One of the key challenges facing Europe in the global digital race is its position relative to major economic competitors such as the United States and China. While these economies have aggressively invested in frontier technologies, platform economies, and digital infrastructures, the EU has struggled to maintain the same pace of digital innovation and adoption (Lee, 2018). The Digital Europe Programme is a response to this challenge, aiming to strengthen the digital capacity of businesses and equip them with the skills and technologies necessary to remain competitive in a rapidly evolving digital economy. While digital inclusion initiatives have historically focused on individuals, there is growing recognition that firms, particularly SMEs, play a crucial role in shaping Europe's digital competitiveness (Skare et al., 2023). Yet, despite policy efforts targeting transformation at multiple levels, disparities persist in how businesses adopt and benefit from digital technologies. Companies continue to experience uneven access to digital infrastructure, skills, and technologies, prompting a critical question: *If digital technologies have become increasingly accessible and their efficiency gains widely recognised,* *why do persistent gaps remain in their adoption and integration across firms?* This paradox calls for deeper investigation into the structural, institutional, and organisational frictions constraining digital uptake. Despite increasing policy attention, firm-level digital disparities demand further exploration in academic and policy discussions to address these challenges and uncover new opportunities.

Understanding the firm-level digital divide requires a multidimensional perspective that moves beyond access to technology and considers structural, institutional, and organisational barriers to digital adoption. This thesis addresses this gap by examining firm-level digital inequalities through the lens of an adapted framework and explores how digital technologies are unevenly distributed among firms and why these disparities persist over time.

The research questions guiding this study are formulated around three core areas and serve to frame the overall direction of the dissertation. First, *what does the existing literature reveal about firm-level digital disparities, and where are the key knowledge gaps?* Second, *how can these disparities be theoretically explained using an adapted framework that incorporates structural and institutional dimensions?* Third, *how do empirical patterns of digital adoption and usage vary across firm sizes, sectors, and regions?* These overarching questions shape the analytical trajectory of the thesis, from the bibliometric analysis in Chapter 2, to the development of a theoretical framework in Chapter 3, and the empirical validation in Chapter 4. In the following sections of this introduction, each of these dimensions is further unpacked and linked to specific questions addressed in the respective chapters. Taken together, these perspectives provide a foundation for understanding the structural dynamics of firm-level digital inequalities and offer insights to inform policy interventions aimed at fostering a more inclusive and balanced digital transformation.

1.5.1. Mapping the Intellectual Structure of the Digital Divide

Chapter 2 of this cumulative dissertation explores the evolution of scholarly output on the digital divide and how the thematic focus of the field has shifted in response to technological developments and broader socio-economic transformations. Through bibliometric techniques, the chapter identifies dominant research streams and highlights underexplored areas, with particular attention to the firm-level digital divide. By analysing both the knowledge base and research front, the chapter provides a systematic overview of where scholarly engagement has been concentrated and where significant gaps remain. This analytical foundation informs the formulation of three research questions that guide the subsequent inquiry into digital inequality.

RQ1. *What have been the main trends and shifts in the focus of digital divide research over time, and how do they shape our current understanding of digital inequalities?*

This question provides a longitudinal perspective on the field, analysing how research priorities have shifted from access-centric studies to more complex, multi-level investigations.

RQ2. *What are the dominant themes and subtopics in digital divide literature, and how are they clustered?*

Using bibliometric techniques, this question identifies key intellectual traditions, influential works, and emerging research frontiers in the field.

RQ3. *How is the firm-level digital divide addressed in digital divide research, and what areas remain largely unexplored?*

This question addresses the gap in firm-level studies, evaluating how businesses are positioned within the discussion and identifying areas that require further investigation.

Addressing these questions maps the intellectual architecture of digital divide research and lays a foundation for subsequent theoretical and empirical investigations. The bibliometric analysis clarifies scholarly focus, identifies blind spots, and highlights the need for deeper exploration of firm-level digital inequalities. This sets the stage for the next chapter, which proposes a theoretical framework to conceptualise digital disparities within and across enterprises.

1.5.2. Conceptualising Firm-Level Digital Disparities

The findings in Chapter 2 highlight both empirical gaps in measuring digital inequalities and theoretical limitations in existing models. These models may not adequately capture the complexities surrounding how disparities in digital technology adoption arise and persist among firms. This is particularly relevant when considering the structural, institutional, and organisational dynamics that influence digital transformation. Rather than concentrating solely on how firms digitalise, this chapter emphasises the importance of understanding the frictions, whether organisational, institutional, or market-based, that affect firms' ability to adopt and utilise digital technologies. Traditional models like the Diffusion of Innovation (DOI), the Technology Acceptance Model (TAM), and the Unified Theory of Acceptance and Use of Technology (UTAUT) have been developed primarily from perspectives in sociology and psychology. These models often focus on individual-level intentions or one-time adoption decisions (Taherdoost, 2018).

Similarly, frameworks such as the Technology-Organisation-Environment (TOE) model, widely applied in information systems research, typically frame digitalisation as a discrete organisational response to environmental or technological incentives (Chatterjee et al., 2021; Souza et al., 2017). However, these perspectives often overlook the cumulative, structural, and knowledge-based aspects of digital inequality that persist across time, sectors, and regions. Considering this, Chapter 3 proposes an adaptation of van Dijk's Resources and Appropriation Theory (RAT) to examine digital disparities among enterprises as multi-dimensional processes shaped by access, skills, and usage, rather than isolated acts of adoption. Building on this conceptual shift, the following section introduces the key research questions that guide the theoretical development of the RTIF.

> **RQ4.** *What are the structural and organisational factors that drive disparities in digital technology adoption among firms, and how do these disparities vary across different firm sizes, sectors, and institutional environments?*

This question seeks to uncover the underlying mechanisms that shape firm-level digital inequalities, considering how structural constraints, economic conditions, and organisational strategies influence digital adoption.

> **RQ5.** *Through what mechanisms do access, skills, and usage interact in shaping firms' digital trajectories, and how do market structures and institutional policies mediate this process?*

This question explores the recursive relationship between a firm's internal capacities and its external environment, offering a framework for understanding how both enterprise-level conditions and systemic influences shape digital disparities.

> **RQ6.** *How do digital disparities among firms persist or transform over time in response to stable technological conditions and punctuated technological disruptions?*

This question aims to explain the temporal dimension of digital inequality, analysing how technological shifts, whether gradual or abrupt, impact the persistence, deepening, or reconfiguration of disparities across firms. Drawing on *punctuated equilibrium*, this perspective acknowledges that digital transformation does not unfold linearly but through phases of stability interrupted by disruptive change. In parallel, *creative destruction* (Schumpeter, 1942) is used to understand how such disruptions can reconfigure competitive positions, enabling some firms to leap ahead while displacing others that fail to adapt, thus generating new forms of inequality.

Collectively, these research questions contribute to developing a theory-informed framework that reflects the complex and layered nature of digital inequalities among firms. This chapter establishes a clearer understanding of how digital transformation occurs unevenly across different organisational contexts by addressing structural conditions, internal capabilities, and institutional dynamics. These theoretical insights provide the basis for the empirical investigation in the next chapter, where the framework is operationalised and tested using firm-level data.

1.5.3. Navigating Digital Divides: Drivers, Impacts and Policy

The question in Chapter 4 delves into the critical heterogeneity observed in the digital transformation process across the economy. Economically, it addresses fundamental issues of productivity, innovation, and inclusive growth, exploring why disparities in digital capabilities persist between large and small firms and across different geographical regions in Italy. Understanding these factors is crucial as differential digital adoption rates can exacerbate existing economic inequalities and impact aggregate economic performance. From a competition standpoint, the question is highly relevant as the ability of firms, particularly SMEs, to move beyond basic digital access towards deeper integration significantly influences their competitiveness, market positioning, and survival prospects in increasingly digitalised markets; barriers to this transition can reinforce market concentration and create asymmetrical competitive conditions among firms. It is essential to identify the mechanisms, such as financial constraints, skill gaps, infrastructural issues, or market failures, that hinder comprehensive digital integration. This identification is vital for creating targeted interventions that promote equitable and widespread adoption of digital technology. Such measures enhance national competitiveness and ensure that the benefits of digitalisation extend across firms of varying sizes, sectors, and regions. The following questions are designed to investigate the conditions under which this broader diffusion of digital capabilities can be achieved.

> **RQ7.** *How do firm size and regional disparities shape the evolution of digital access, skills, and usage, and what mechanisms prevent firms from transitioning from basic access to full digital integration?*

This question explores the role of firm-level heterogeneities in shaping digital adoption patterns. By analysing firm size and regional variations, it investigates whether digitalisation efforts are narrowing or exacerbating inequalities, particularly in resource-limited regions.

RQ8. *To what extent do sectoral characteristics and firm-specific capabilities determine the trajectory of digital adoption, and how do these factors contribute to persistent inequalities in digital integration?*

This question examines how industry-specific requirements and firm-level capabilities influence digital adoption. It considers whether firms in ICT-intensive sectors are more likely to transition towards advanced digital usage than those in traditional industries, and how firm-specific resources mediate this process.

RQ9. *What types of policy interventions can effectively bridge the second-level digital divide, ensuring that access improvements translate into meaningful skill development and technology integration rather than reinforcing existing inequalities?*

This question evaluates the effectiveness of current policy frameworks, such as the Digital Europe Programme, in addressing second-level digital inequalities. It aims to identify whether existing measures sufficiently tackle the systemic challenges firms face and what interventions are most effective in enabling full-scale digital transformation across diverse organisational contexts.

The research questions formulated across the three chapters collectively represent a layered and interdisciplinary inquiry into firm-level digital inequalities. From mapping the intellectual evolution of the digital divide to developing a tailored theoretical framework and finally empirically validating it with firm-level data, this dissertation provides an integrated perspective on how digital transformation unfolds unevenly across enterprises.

1.6. Overview of the Chapters

Table 1 outlines the structure of the dissertation by summarising the main chapters, including their analytical focus, guiding research questions, data sources, methodological approaches, and temporal scope. This summary illustrates the progression of the study from identifying conceptual gaps to proposing a theoretical framework, and ultimately testing it empirically with firm-level data.

Chapter	Subject of Analysis	Main Focus	Research Questions Addressed	Data Sources	Method	Temporal Scope
2	Literature Review	Identifying gaps in digital divide research, focusing on firm-level disparities	1. What have been the main trends and shifts in digital divide research over time? 2. What are the dominant themes and subtopics in digital divide literature? 3. How is the corporate digital divide addressed in research, and what gaps remain?	Bibliometric databases, academic literature	Bibliometric analysis (co-citation, keyword clustering)	2000 - 2022
3	Theoretical Framework	Developing the RTIF for firm-level digital inequalities	1. How do firm-level digital disparities persist despite policy interventions? 2. How do access, skills, and usage interact in shaping firms' digital trajectories? 3. How do sectoral and institutional factors shape digital adoption?	Literature on digital transformation, institutional economics, and innovation studies	Conceptual framework adaptation, theoretical analysis	N/A
4	Empirical Analysis	Testing RTIF through firm-level data to quantify digital disparities and their evolution	1. How do firm size and regional disparities shape digital access, skills, and usage? 2. To what extent do sectoral characteristics and firm-specific capabilities determine digital adoption? 3. What types of policy interventions effectively bridge the second-level digital divide?	Firm-level survey data (Eurostat, ISTAT), sectoral reports	Factor Analysis, Multiple Correspondence Analysis, Gini index	2014 - 2019

Table 1: Synthesis of the dissertation chapters by focus and approach.

1.6.1. Overview of Chapter 2: Bibliometric Analysis of European Research on the Digital Divide

The literature on the digital divide offers substantial insights into inequalities at the individual and household levels, highlighting critical issues related to access, skills, and usage of digital technologies. These contributions are particularly relevant for addressing questions of social inclusion and equity. However, as digital transformation increasingly permeates economic production, it also reshapes labour markets, redefines business models, and generates new patterns of innovation and competition (Ciarli et al., 2021; Jerome et al., 2024; Øverby & Audestad, 2021; Trischler & Li-Ying, 2023). These benefits, while transformative, are distributed unevenly across micro, meso, and macro levels, raising new questions about how digital disparities manifest among enterprises. Despite these shifts, firm-level digital inequalities remain relatively underexplored in the academic literature. This chapter addresses that gap by conducting a bibliometric analysis of European research on the digital divide, with the aim of identifying major trends, intellectual influences, and underrepresented areas, particularly those related to the corporate digital divide (Castillo-Tellez, 2023).

The study is based on a dataset of 1,609 scientific publications spanning 2000 to 2022, sourced from Web of Science, Scopus, and Dimensions. To analyse the evolution of the field, three bibliometric techniques were employed: (i) performance analysis to assess publication and citation trends, (ii) science mapping using co-citation and bibliographic coupling to identify key intellectual influences, and (iii) network analysis to visualise collaborative structures and thematic clusters (Donthu et al., 2021). The study also categorises the evolution of digital divide research into three periods: 2000–2007, 2008–2015, and 2016–2022, capturing thematic shifts from access disparities (first-level digital divide) to differences in skills and usage (second-level digital divide) and, more recently, outcome-based inequalities (third-level digital divide) (Ragnedda, 2017; J. van Dijk, 2020).

The findings reveal notable shifts in research focus. Early studies (2000–2007) concentrated on access disparities, reflecting concerns about internet availability and infrastructure (Norris, 2001). The second period (2008–2015) saw an increasing focus on digital skills and usage inequalities, highlighting differences in digital competencies and the ability to leverage technology effectively (Hargittai, 2002). More recently (2016–2022), research has turned towards the consequences of digital inequalities, particularly economic and social outcomes, illustrating how disparities in digital adoption translate into broader socio-economic divides (van Deursen & Helsper, 2015).

Despite these advancements, the study identifies a significant gap in research on the firm-level digital divide. Of the 1,609 documents analysed, only 30 directly addressed corporate digital disparities, underscoring a major research gap (Castillo-Tellez, 2023). While most studies focus on individuals, firms face distinct challenges in digital adoption, such as financial constraints, sectoral demands, and technological dependencies, which remain largely unexplored in the literature (Bach et al., 2013; Cirera et al., 2022).

The bibliometric analysis also highlights key theoretical foundations within digital divide research. The RAT developed by van Dijk (2005) and the Diffusion of Innovations (DOI) framework by Rogers (2003) remain dominant. However, these theories predominantly address digital disparities at the individual level, lacking an explicit focus on firm-level inequalities. This theoretical limitation further underscores the need for an adapted framework that can effectively analyse digital disparities among enterprises.

In addition, the study maps leading research institutions and countries contributing to digital divide research. The University of Twente and the London School of Economics serve as central hubs of scholarly activity, with the United Kingdom, the Netherlands, and Spain being the most prolific contributors. Strong international collaborations also signify an increasingly global approach to digital divide studies, while still maintaining a focus on individual-level disparities (Chipeva et al., 2018; Livingstone & Helsper, 2007).

By conducting this bibliometric analysis, this study not only identifies a literature gap but also reveals a theoretical gap. While existing frameworks provide valuable insights into digital disparities, they fail to fully capture the complexities of digital adoption at the firm level. This realisation informs the second chapter, where the theoretical gap is addressed through the adaptation of van Dijk's RAT into the RTIF, providing a comprehensive model for analysing digital disparities in enterprises.

1.6.2. Overview of Chapter 3: Assessing Digital Integration in Firms: A Framework for Disparities in Access, Skills, and Usage

This chapter provides a theoretical examination of the digital divide among firms through the development of the RTIF. Building on Van Dijk's RAT, the RTIF is adapted to account for firm-level contextual factors, including firm size, sectoral heterogeneities, regional differences, institutional dynamics, and the market structures of digital technologies. This chapter thoughtfully considers the limitations of established models, including the Diffusion of Innovations (DOI) proposed by Rogers (2003) and the Technology-Organisation-Environment (TOE) framework introduced by Tornatzky & Fleischer (1990). While these models offer valuable insights into technology adoption, they do fall short in thoroughly addressing the ongoing digital disparities observed across various firms.

The study employs a structured theory adaptation approach consisting of three methodological steps: (i) historical contextualisation of digital disparities, (ii) conceptual evaluation of existing frameworks, and (iii) theoretical integration of firm-level constructs with digital adoption dynamics (Crossler et al., 2018; Weber, 2012). The RTIF broadens the scope of analysis beyond foundational technologies such as internet connectivity to advanced digital tools, including artificial intelligence, cloud computing, and predictive analytics. These technologies are reshaping business processes, disrupting established routines, and introducing new competitive dynamics, yet their uneven adoption further accentuates existing disparities (Baldwin, 2019; Siebel, 2019).

The chapter examines the three core constructs of RTIF access, skills, and usage, and their interactions in shaping digital transformation. Access encompasses a firm's availability of digital infrastructure, connectivity, and computing resources, while skills capture its internal capabilities to leverage digital tools effectively. Usage examines the extent to which firms integrate digital technologies into core business operations (e.g., marketing and management) (Cirera et al., 2022; Shakina et al., 2021). By incorporating these constructs with external influences such as institutional policies and technological disruptions, the RTIF offers a dynamic model for understanding firm-level digital inequalities.

A key contribution of this chapter is its distinction between stable and disruptive periods in digital adoption trajectories. Firms experience incremental technological integration during stable periods, while punctuated events, such as policy changes or breakthrough innovations, accelerate or hinder the adoption of new technologies. This conceptualisation resonates with Schumpeter’s (1942) theory of creative destruction, wherein waves of innovation disrupt existing equilibria, enabling entrepreneurial firms to seize new opportunities while rendering others obsolete. In the context of digital transformation, technological disruptions act as selective forces: firms with the capabilities to reconfigure their access, skills, and usage trajectories are more likely to thrive, whereas others may struggle to adapt or exit the market altogether.

Furthermore, the framework acknowledges that adaptation is not determined solely by internal capabilities but is heavily mediated by institutional environments and market structures. Institutions play a critical role in shaping firms' capacity to navigate disruptive periods by providing supportive infrastructures, incentives, and regulations that foster resilience, or by reinforcing existing disparities through uneven policy implementation (Nicoletti et al., 2020; Schildt, 2017). Thus, the RTIF not only conceptualises digital transformation as a dynamic and discontinuous process but also situates it within broader structural and institutional dynamics that condition the outcomes of technological change.

This chapter addresses the theoretical gap identified in Chapter 2 and provides the conceptual foundation for analysing firm-level digital disparities. It also lays the groundwork for empirical validation in Chapter 4, where the RTIF is tested using firm-level data from Italy to assess its explanatory power in real-world digital adoption dynamics.

1.6.3. Overview of Chapter 4: Empirical Analysis of Digital Disparities in Italian Enterprises

This chapter presents the empirical validation of the RTIF by examining digital disparities among Italian firms. Building on the theoretical foundation established in Chapter 2, this study applies RTIF to firm-level data, measuring access, skills, and usage to assess digital adoption patterns across enterprises of varying sizes, sectors, and regions. Using survey data on ICT usage in enterprises from 2014 to 2019, the analysis employs Factor Analysis of Mixed Data (FAMD) and Multiple Correspondence Analysis (MCA) to develop composite indices for digital access, skills, and usage, allowing for a robust measurement of digital disparities.

The empirical strategy employs a repeated cross-sectional design, ensuring a comprehensive examination of digital transformation trends over time. Additionally, the Gini coefficient is employed to quantify inequalities within these indices, offering a measure of digital disparities across firm characteristics. Key findings reveal that while progress has been made in digital access, substantial gaps remain in skills and usage, particularly among SMEs and firms in the southern regions of Italy (Bratta et al., 2020; Cirera et al., 2022). Larger firms demonstrate greater access to digital infrastructure and a higher degree of technology integration, whereas SMEs face constraints related to financial resources, workforce capabilities, and regional disparities.

Sectoral analysis highlights variations in digital adoption, with advanced industries such as ICT and creative industries, and services exhibiting higher levels of integration, while traditional sectors, including manufacturing and retail, struggle with digital transformation. The regional analysis further underscores persistent geographical disparities, with northern firms consistently outperforming their southern counterparts in digital adoption and integration. These findings reinforce the necessity of targeted policy interventions to support skill development and technological adoption, particularly for lagging sectors and regions.

The analysis highlights the necessity for policy interventions that extend beyond merely increasing digital access. Specific strategies are essential to tackle ongoing skill disparities and to promote deeper incorporation of digital technologies into the operational processes of businesses. Key recommendations comprise: (1) broadening digital upskilling programmes designed for SMEs and traditional sectors, where skill disparities are most evident; (2) encouraging advanced technology adoption through tax incentives or matching grants, especially for companies in underdeveloped regions; (3) facilitating the growth of digital infrastructure alongside workforce development efforts to ensure that access leads to meaningful use; and (4) promoting partnerships between the public and private sectors to establish regional hubs that combine digital training, innovation networks, and financial assistance. These interventions are crucial for bridging the second-level digital divide and enabling Italian enterprises of all sizes and sectors to thrive in an increasingly digital economy. By empirically validating the RTIF, this chapter bridges the theoretical insights from Chapter 2 with real-world digital adoption dynamics, reinforcing the need for an integrated approach to understanding firm-level digital disparities.

1.7. Conclusions and Avenues for Future Research

1.7.1. Main findings

The bibliometric analysis in Chapter 2 addresses research questions on the evolution and thematic structuring of digital divide research in Europe. RQ1 examines temporal shifts in focus, showing a move from basic access inequalities (Jan. van Dijk & Hacker, 2003) to complex issues of digital competencies and usage patterns, reflective of the second-level divide (van Deursen & van Dijk, 2011; van Dijk & van Deursen, 2014). The latest phase, shaped by broader societal changes like the COVID-19 pandemic, has increased focus on the third-level digital divide, addressing inequalities in digital outcomes and engagement with technologies (Friemel, 2016; Iivari et al., 2020).

In response to RQ2, the bibliometric mapping technique uncovered distinct thematic clusters, capturing the diversification and deepening of digital divide scholarship. Initially dominated by conceptual explorations of physical access (Norris, 2001), the literature now prominently features discussions around differentiated digital skills and usage outcomes, thus expanding beyond mere connectivity to consider qualitative engagement and demographic-specific dimensions (Hargittai, 2002; Scheerder et al., 2017).

Addressing RQ3 reveals a significant gap in firm-level digital divide research. Despite extensive engagement, only a small fraction (30 out of 1609 documents) examined digital inequalities at the enterprise level. This gap offers opportunities for further exploration, given its potential to enhance competitiveness, drive innovation, and support regional development (Bach et al., 2013; Cirera et al., 2022). Studies show disparities based on enterprise size, sector, and location (Torrent-Sellens, 2024). This research enriches the digital divide discussion by focusing on the firm level, providing insights into how academic literature aligns with the challenges of the EU's Digital Europe Programme, which aims for an equitable digital transformation for individuals, enterprises, and governments. By identifying the current state, thematic evolution, and research gaps, particularly regarding firm-level inequalities, this analysis offers empirical evidence and clarity essential for informing EU policy and strategic initiatives. The ongoing evolution of digital technologies indicates that digital disparities are a constantly changing challenge. Therefore, examining firm-level digital divides offers vital insights for equitable technological integration and sustained competitiveness.

The theoretical analysis in Chapter 3 addresses RQ4, RQ5, and RQ6 by advancing a comprehensive framework to explain firm-level digital disparities. RQ4 investigates structural and organisational conditions influencing digital adoption. Findings reveal that firm size, sectoral characteristics, and institutional environments significantly shape digital integration, with larger firms typically enjoying greater capacity to adopt digital technologies, while smaller firms encounter compounded financial, human, and regulatory barriers. In response to RQ5, the study introduces the RTIF, which reconceptualises access, skills, and usage as recursively interlinked constructs. These dimensions are shown to evolve in interaction with external market structures and institutional interventions, highlighting path dependency and feedback effects within firms' digital trajectories. RQ6 is addressed through the integration of punctuated equilibrium theory, which elucidates how technological disruptions and regulatory changes periodically destabilise established trajectories, creating windows of opportunity and risk that disproportionately affect firms with differing adaptive capacities. This perspective aligns with Schumpeter's notion of creative destruction, where innovation not only drives progress but also displaces incumbent structures, amplifying inequalities among firms with uneven capacities to adapt or innovate in response to these shifts. Collectively, these theoretical contributions move beyond linear models by situating digital disparities within complex institutional and evolutionary dynamics, offering a robust lens for understanding how persistent inequalities are structured and sustained in digitally transforming economies.

The empirical analysis in Chapter 4 addresses RQ7, RQ8, and RQ9 by examining structural digital disparities among Italian firms using composite indices for access, skills, and usage. RQ7 investigates the influence of firm size and regional variation, revealing that while access disparities have declined steadily, particularly following policy incentives like the 'iper-ammortamento' tax measure, inequalities in skills and usage persist, especially among SMEs and firms in Southern and Insular regions. RQ8 focuses on sectoral and firm-specific capabilities, showing that ICT and creative industries exhibit higher digital integration, while industrial and service sectors struggle with skills development and effective usage, indicating that sectoral trajectories are neither automatic nor uniform. RQ9 is addressed by highlighting the limitations of policies narrowly focused on infrastructure. The findings underscore that without complementary investments in organisational capabilities and workforce development, improvements in access alone risk exacerbating the second-level digital divide. Overall, the study empirically validates the recursive structure of the RTIF and emphasises the need for balanced, multi-dimensional policy approaches that foster inclusive digital transformation across heterogeneous firm contexts.

1.7.2. Theoretical Contributions

This dissertation makes a distinct theoretical contribution by adapting and extending existing frameworks to more adequately capture digital inequalities at the firm level. Building upon Van Dijk's RAT, the study proposes the RTIF, which reinterprets the constructs of access, skills, and usage not as static categories but as dynamic, interdependent processes embedded within organisational and institutional contexts. This reconceptualisation is theoretically significant, as it shifts the unit of analysis from individuals to enterprises, allowing for a more nuanced understanding of how digital disparities manifest within firms of varying capacities, sectors, and institutional environments.

Furthermore, by integrating insights from institutional economics, the RTIF foregrounds how structural constraints such as market concentration, regulatory asymmetries, and access to enabling institutions shape the distribution and appropriation of digital resources. This enriches the explanatory power of the framework by highlighting how external institutional arrangements interact with internal firm characteristics to reproduce or mitigate digital inequalities.

Incorporating punctuated equilibrium theory further advances the literature by providing a temporal and evolutionary dimension to digital transformation. Unlike models that assume linear or continuous progress, this approach accounts for the uneven, often disruptive nature of technological change. It enables a deeper understanding of how external shocks, such as regulatory reforms or technological innovations, can trigger abrupt shifts in firms' digital trajectories, often amplifying disparities in firms' adaptive capacities. This perspective resonates with Schumpeter's notion of *creative destruction*, wherein technological innovation acts as both a catalyst for progress and a force of structural displacement. By linking punctuated shifts in digital infrastructure and capabilities to systemic reconfigurations within markets and industries, the framework explains how certain firms thrive while others fall behind, offering a theoretically grounded account of divergence in digital transformation outcomes.

Ultimately, the framework prompts a reevaluation of the concept of the digital divide itself. Rather than treating access, skills, and usage as sequential stages or isolated variables, RTIF conceptualises them as a recursive system conditioned by firm-specific and systemic factors. This systemic view contributes to theory-building in digital inequality research by offering a flexible yet robust architecture that can integrate firm-level heterogeneity, path dependency, and structural influences within a single analytical model.

1.7.3. Policy Implications

The findings of this dissertation carry significant implications for policy design aimed at reducing digital inequalities across the firm landscape, particularly in structurally diverse and institutionally fragmented contexts such as Italy. First, the results challenge infrastructure-centric approaches that treat connectivity as a sufficient condition for digital inclusion. While improvements in physical access enabled by national broadband plans and EU structural funds have helped reduce some first-level disparities, persistent gaps in digital skills and meaningful usage, especially among SMEs and firms in lagging regions, underscore that access alone is insufficient for inclusive digital transformation.

This highlights the need for integrated and layered policy frameworks that link infrastructure development with the enhancement of organisational capabilities, workforce readiness, and sector-specific digital strategies. Interventions must extend beyond providing access to actively supporting firms' ability to appropriate and integrate digital technologies. This includes policies that promote internal ICT training, offer digital toolkits tailored to sectoral needs, and support local platforms that facilitate peer learning and ecosystem collaboration. Such an approach would be especially impactful for SMEs, which often lack the absorptive capacity or digital maturity to independently implement advanced technologies.

Moreover, the recursive interdependence between access, skills, and usage central to the RTIF framework calls for sequenced and adaptive policy design. Interventions that assume a linear or uniform progression through digital transformation risk misallocating resources or entrenching disparities. Instead, policy tools must recognise the feedback loops within firms' digital trajectories, such as how inadequate skills can inhibit technology usage even when infrastructure is available and respond with flexible, context-sensitive mechanisms.

The empirical results also reinforce the relevance of place-based digital strategies. Disparities observed across Italian macro-regions, particularly between northern industrial hubs and southern or insular regions, reflect the broader challenge of tailoring digitalisation policies to uneven institutional and economic landscapes. Institutional quality, as measured by the IQI[3], emerges as a critical enabling condition. This finding supports the design of granular, territory-sensitive interventions, co-developed with regional stakeholders, chambers of commerce, and local innovation centres. It also aligns with the EU's vision for a "digitally cohesive" Union, where cohesion policy complements digital competitiveness.

Furthermore, the findings highlight the limitations of a one-size-fits-all governance framework, particularly in the face of market asymmetries. Italy's experience illustrates how digital lock-in and reliance on foreign technology providers (especially in cloud infrastructure, AI, and platform services) create strategic dependencies that require robust governance responses. These include European-level regulatory mechanisms such as the Digital Markets Act (DMA), Digital Services Act (DSA), and the AI Act, which aim to foster fair competition, safeguard data governance, and establish transparency in algorithmic decision-making. Although these frameworks were formalised after the period studied (2014–2019), their emergence reflects underlying concerns already visible in Italy's digital ecosystem. Thus, anticipatory and

[3] The Institutional Quality Index (IQI), developed by Nifo and Vecchione (2014), measures institutional quality in Italian provinces and regions across five dimensions: voice and accountability, government effectiveness, regulatory quality, rule of law, and corruption. It uses various data sources and covers the years 2004–2019

complementary national policies are needed to avoid deepening structural dependencies while strengthening local digital sovereignty and resilience.

Finally, the theoretical contribution of this dissertation, particularly the integration of punctuated equilibrium theory and Schumpeterian dynamics, underscores the importance of forward-looking and disruption-aware policymaking. Digital transformation does not unfold smoothly; it often accelerates through bursts of innovation or exogenous shocks. This demands anticipatory governance tools that can respond not only to diffusion gaps but also to displacement risks, such as technological obsolescence or workforce exclusion. Strategic foresight, continuous policy learning, and cross-sector coordination will be essential to ensure that digitalisation reduces rather than reinforces long-standing inequalities.

1.7.4. Limitations and Future Research

This dissertation advances the study of the digital divide among enterprises through a combination of bibliometric, theoretical, and empirical approaches. Each chapter offers a distinct perspective, mapping the evolution of the field, proposing a novel theoretical framework, and empirically operationalising key constructs. However, each component also has methodological and conceptual limitations that warrant critical reflection and present opportunities for further research.

The bibliometric analysis in Chapter 2 provides a structured and exploratory overview of digital divide scholarship in Europe. While it offers valuable macro-level insights into thematic evolution and intellectual clusters, its scope is shaped by the limitations of citation-based databases and metadata-dependent metrics. For instance, citation counts do not capture the rhetorical intent of a citation, whether it supports, critiques, or references a concept, which complicates the interpretation of scholarly influence. Furthermore, while bibliographic coupling allowed for the identification of epistemic clusters, it may oversimplify the internal diversity and interdisciplinarity of contributions. Given the moderate size of the dataset, advanced text-mining techniques such as topic modelling were not employed. Future research could expand this strand by integrating mixed-method bibliometrics, such as topic modelling, sentiment analysis or qualitative coding of citation contexts, to map how firm-level digital inequality has evolved conceptually and methodologically across disciplines.

Chapter 3 introduces the Resources and Technology Integration Framework (RTIF), which adapts van Dijk's Resources and Appropriation Theory (RAT) for the enterprise context and enriches it with insights from institutional economics and punctuated equilibrium theory. This framework provides a valuable perspective on the recursive relationship between access, skills, and usage; however, it remains mostly conceptual at this stage. Future research should aim to formalise the RTIF into a testable model, potentially through simulation studies or system dynamics modelling, which would help capture the complex dynamics at play. Furthermore, certain crucial aspects, such as informal organisational routines, digital leadership, firm culture, and decision-making hierarchies, have not been thoroughly explored but could have a significant impact on technology adoption trajectories. To address this, researchers could conduct organisational ethnographies, case studies, or surveys that take into account the soft variables influencing the development of digital capabilities. Additionally, future studies could incorporate an outcomes dimension, focusing not only on technology adoption but also on the effects of digitalisation on productivity, innovation, competitiveness, and economic growth. Risks such as cybersecurity threats, data misuse, or negative returns on digital investments due to poor implementation or insufficient skills should also be examined. By incorporating outcomes, researchers can gain a more comprehensive understanding of the trade-offs and value creation associated with digital transformation.

The empirical analysis in Chapter 4 constructs composite indices of access, skills, and usage using factor-analytic techniques and examines disparities by firm size, sector, and region. While the composite approach provides analytical clarity and enables multidimensional comparisons, it also entails a degree of construct simplification. Index construction, by design, abstracts from intra-firm variation and may obscure sector-specific meanings of digital capabilities. Furthermore, the analysis is based on repeated cross-sectional data, which limits the ability to trace firm-level digital trajectories over time or to infer causal relationships between constructs. The challenge of potential endogeneity, particularly among interdependent constructs such as access and usage, also remains. Future research could address these limitations through panel data approaches, quasi-experimental designs, or structural equation modelling, where feasible. Additionally, expanding this analysis beyond the Italian context would test the transferability of the RTIF and the composite indicators across institutional settings. Comparative studies across EU member states or between advanced and emerging economies could shed light on how national innovation systems mediate firm-level digital inequalities. Another promising direction is to develop a usage index that captures the uptake of more advanced or frontier technologies, such as artificial intelligence, automation, and advanced analytics, which can offer a more comprehensive picture of the digital technology stack. This would also allow researchers to examine how these technologies may reduce, complement, or substitute existing digital skills, and what new forms of inequality might emerge as a result.

Finally, the inclusion of policy frameworks and structural contexts, while enriching the interpretive scope of the study, could be further expanded through closer engagement with policymakers, innovation intermediaries, and regional actors. Participatory research designs or policy co-creation case studies could generate insights into how digitalisation policies are experienced, resisted, or adapted by different types of firms. These efforts would help close the loop between analytical modelling and policy relevance, and strengthen the link between academic research and actionable strategies for digital inclusion.

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Chapter 2 - Bibliometric Analysis of European Research on Digital Divide: An Exploration of the Firm-level Landscape

Abstract: This research provides an exhaustive analysis of the European digital divide literature's evolution and current state, particularly emphasising the often underexplored firm-level sector. The digital divide, denoting disparities in digital access, literacy, and fluency, has become a critical concern in the era of rapid digital transformation. Despite its significance, research on the firm-level digital divide is limited. This study aims to address this gap to advance in different research avenues on digital disparities in the business realm. Using a dataset of 1609 documents published from 2000 to 2022, extracted from Web of Science, Scopus, and Dimensions, the study employs three bibliometric techniques: performance analysis, science mapping, and network analysis to examine the research landscape, including scientific output, impact, and intellectual structure within the field. The research uncovers key trends and shifts in European digital divide research across three distinct periods (2000-2007, 2008-2015, 2016-2022). It highlights the evolution of research themes from access inequalities to a nuanced understanding of skills and usage disparities, reflecting the multifaceted nature of the digital divide. The study reveals a significant gap in the literature regarding the firm-level digital divide, with only 30 out of the 1609 documents directly addressing this area. It further identifies leading institutions, publications, and thematic clusters in digital divide research, emphasising the role of intellectual interactions and thematic connections in shaping the field.

Keywords: Digital divide, bibliometric analysis, literature review, European research, firms.

JEL Classification: O33, 052, D83, L86, C55.

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2.1. Introduction

The rapid advancement of digital technologies has transformed different aspects of our daily lives. As a result, the digital divide - the disparity among actors in society and the economy who lack access, literacy, and fluency in digital technologies - has emerged as a significant concern for policymakers and researchers. The digital divide is a term used interchangeably with the digital gap, digital inequality, and digital disparity, which began to gain more attention among researchers and policymakers in the mid-1990s. At that time, the scientific community began the first attempts to conceptualise factors, effects, and causes of the digital divide compelled by the new technological paradigm.

Following Regneda (2017), van Deursen and Helsper (2015) the extensive body of research on the digital divide has distinguished three waves of research, each building upon the previous to expand our understanding of the concept. The first wave, which started in the mid-1990s, resulted from the computerisation and commercialisation of the internet and focused on the inequalities that arose from the unequal distribution of computer technology and internet access, known as the first-level digital divide. During the second wave of research, the focus shifted to examining the technology adaptability of individuals and how exposure to existing technologies could lead to exclusion and inequality for those who have or lack the skills to use digital technologies and navigate the digital world. This emphasis on skills and usage led to a more nuanced understanding of what is known as the second-level digital divide. The third wave of research builds upon the inequalities identified in the first and second levels. This wave shifts the focus to analysing the disparities in the outcomes individuals receive even if they have access and adequate skills but differing levels of internet usage.

Although digital technologies have gained prominence and extensive research has been conducted on the digital divide in Europe, the majority of studies have concentrated on the divide among households, individuals, and demographic groups (Elena-Bucea et al., 2021; Livingstone & Helsper, 2007; Ragnedda, 2017; van Deursen & van Dijk, 2014; van Dijk & Hacker, 2003) rather than businesses. While this focus on households and individuals offers crucial insights into the digital divide, Bach et al. (2013), Cirera et al. (2022) and Shakina et al. (2021) argue that a deeper understanding of the divide within the enterprises is necessary. This divide is particularly relevant for European enterprises, as it can impact their competitive advantage, innovation potential, and contribution to regional economic development.

While global scholarship, particularly from the United States and more recently China, has played a leading role in theorising and driving digital transformation, the present study deliberately narrows its focus to European research. This decision is not merely methodological but analytical. Europe's digitalisation trajectory differs markedly from that of the global technological front-runners (Miller, 2022). The region lags behind the U.S. and China in the development, deployment, and adoption of digital technologies, and it faces persistent challenges to technological sovereignty due to its reliance on U.S.-based platforms and providers (Lee, 2018). These dependencies create distinctive vulnerabilities in areas such as cloud services, data governance, artificial intelligence ecosystems, and semiconductor supply chains. At the same time, internal divides within Europe between large and small firms, northern and southern regions, and sectors with different capacities to absorb digital tools highlight the need to examine digital gaps not only as issues of access but also as mismatches between the supply and demand of skilled labour and the organisational capacities to use digital technologies effectively. For this reason, analysing European scholarship allows us to capture how these unique structural and institutional conditions shape the research agenda on digital divides, particularly at the firm level. Anchoring the bibliometric analysis in Europe also ensures direct relevance to the EU's Digital Decade and Digital Europe Programme, which explicitly aim to address these divides and to enhance Europe's competitiveness in the global digital economy.

The main objective of this study is to provide a comprehensive understanding of the current state of European research on the digital divide by utilising three bibliometric techniques, including performance analysis, science mapping, and network analysis. These analytical tools will allow a broader examination of the research landscape, including scientific output, impact, and intellectual structure within the field.

By applying a combination of techniques such as citation and co-citation analysis, bibliographic coupling, and network analysis, this study not only aims to identify leading publications, authors, themes, and collaborations within the field but also to visualise the intellectual structure and evolution of the field over time. This integrated analysis will also facilitate a more exhaustive exploration of the firm-level digital divide and provide insight to answer the following research questions through a holistic lens:

> **RQ1**. *What have been the main trends and shifts in the focus of European research on the digital divide over time, and how does the intellectual structure and the thematic relationships shape the current state of knowledge in this field?*

RQ2. *What are the key themes and subtopics related to the digital divide in European research, and how are they grouped or clustered in the literature?*

RQ3. *How is the firm-level digital divide addressed in European research on the digital divide, and what areas have been largely unexplored in this field?*

An analysis of 1609 scientific publications between 2000 and 2022 collected from three different data sources (the Web of Science, Scopus, and Dimensions) is conducted in this study to answer these research questions. Furthermore, by merging bibliographical information from these data sources, this study sets itself apart by employing a broader and diverse range of bibliographical data on the digital divide. This approach enables a more comprehensive investigation of scientific output and the influence of European research in the field. Moreover, the study will assess the most impactful research across three distinct periods (2000-2007, 2008-2015, and 2016-2022) to evaluate the literature's evolution and novel findings. Prior bibliometric studies on the digital divide have concentrated on specific fields, such as health sciences or computer science. By extending the application of bibliometric analysis beyond these fields, diverse insights may emerge. Additionally, the absence of a particular focus on the digital divide within the European context underscores the need for further exploration in this region.

2.2. Literature Review

2.2.1. Digital Divide: An Evolving Concept

The widespread adoption of the Internet and computer technologies in the late 1990s marked a turning point in the ongoing digital and technological revolution, while concurrently giving rise to a new form of inequality. This inequality, later acknowledged as the "digital divide" in US government policy reports, ignited a nationwide debate. In Europe, seminal research by Norris (2001), Castells (2002), James (2002), Dutton et al. (2004), and Selwyn (2004) initially framed the digital divide as a binary issue, commonly referred to as the first-level digital divide. This divide drew a clear distinction between those with and without access to the internet and computer technologies. Despite the evolving concept of the digital divide, recent studies such as Conrad et al. (2019) and Bychkova et al. (2020) underscore that certain socioeconomic groups and remote regions continue to face substantial barriers to access, suggesting that the matter of access remains relevant. In response to this ongoing concern, other research, including McMenemy(2022), offers policy recommendations that advocate for internet access as a fundamental right, emphasising the interrelated nature of these various perspectives on the digital divide.

While this early definition of the digital divide as a dichotomous matter of technology access was a starting point for discussions, subsequent research by van Dijk (2005; 2006), van Deursen and van Dijk (2010), van Deursen and van Dijk (2014), and Hargittai (2002) evolved this understanding into a more nuanced and multidimensional approach, referred to as the second-level digital divide. These researchers contended that with the increasing ubiquity of technology access, disparities in internet usage and digital skills could exacerbate the divide. This body of work suggests that the divide extends beyond mere access to technology, encompassing the ability to effectively search, access, and evaluate information using digital technologies. In line with this perspective, additional research, such as studies by González et al. (2017) and Spada et al. (2022), posits that developing digital skills during higher education could be essential in mitigating the second-level digital divide.

With the rapid advancement of technologies, scholars such as van Deursen and Helsper (2015), Regneda (2017), and Sheerder et al. (2017) have further expanded the definition of the digital divide to encompass what is now referred to as the third-level digital divide. They argue that despite individuals having independent access and sufficient skills, disparities may still arise due to variations in the returns obtained from internet usage.

As highlighted by Regneda (2017), the third-level digital divide investigates the impact of digital technologies on individuals' lives, focusing on enhancing personal and professional aspects through the capacity to benefit from digital technologies in a data-driven market. Building on this perspective, recent research by De Marco (2022) and Merisalo and Makkonen (2022) emphasises that fully leveraging the potential of digital technologies depends on access to the latest advancements and proper utilisation that aligns with the user's goals. The third-level digital divide highlights the interconnected nature of the various dimensions of the digital divide and the need for a deeper understanding of the issue.

The digital divide, as a concept, has undergone substantial transformations as technology advances. According to Regneda (2017), to remain relevant and accurate, any definition of the digital divide must keep pace with technological advancements to provide a solid and relevant understanding of the concept. Furthermore, Van Dijk (2003) demonstrated that the digital divide is a complex and dynamic phenomenon, reflecting the rapidly changing landscape of technology and the multifaceted complexities that it brings to society.

2.2.2. Complexities of the Digital Divide

As we delve into the evolving nature of the digital divide, it is essential to recognize the multiple complexities researchers face when examining this multifaceted phenomenon. Following van Dijk (2005), Helsper (2012), Regneda (2017), and Regneda and Kreitem (2018), the digital divide's emergence is deeply intertwined with existing social and economic disparities. For example, numerous studies have demonstrated the interplay of the digital divide with various demographic variables such as income (Elena-Bucea et al., 2021; Fuchs, 2009; Ragnedda & Muschert, 2013; van Deursen et al., 2015; van Dijk & Hacker, 2003), education (Becker, 2022; Cruz-Jesus et al., 2016; Eynon, 2009; Pieper et al., 2003; Santos et al., 2013; Selwyn et al., 2001); age (Agudo-Prado et al., 2012; Camerini et al., 2018; Livingstone & Helsper, 2007; Marimuthu et al., 2022; Niehaves & Plattfaut, 2014; Paul & Stegbauer, 2005), gender (Mariscal et al., 2019; Minguez, 2005; Picatoste et al., 2022; van Deursen et al., 2015; Winker, 2005), race and ethnicity (Bartikowski et al., 2018; D'Haenens et al., 2007; Gladkova et al., 2022; Milioni et al., 2014; Spaiser, 2011; Jan. van Dijk & Hacker, 2003).

Studies like James (2002), Andrés et al. (2010), Dutt and Kerikmäe (2014), and di Prisco and Strangio (2021) have examined the macro-dimensions of the digital divide, delving into global disparities in internet penetration, infrastructure, and connectivity within low- and high-income countries. Other works have focused on how geography determines access and connectivity (Blank et al., 2018; Ferro et al., 2005; Gómez-Barroso & Pérez-Martínez, 2007; Palop García et al., 2014; Rodríguez-Hevía et al., 2022; Taipale, 2013). Additionally, investigations by Norrris (2001); Kolsaker and Lee-Kelley (2006); Fernandez-Prados et al. (2021), and Natalia (2022) have explored the impact of the digital divide on democracy, assessing its influence on political participation and civic engagement. They have also scrutinised how digital technologies shape the interactions between individuals and governments.

2.2.3. Frameworks and Methodologies in the Study of the Digital Divide

Interdisciplinary collaboration is vital in comprehending the complex issue of the digital divide. Van Dijk (2017) illustrates that early research involved experts from multiple fields, such as communication science, sociology, psychology, economics, and education science. As digital technologies were diffusing, experts from additional fields, such as informatics, information systems, business, management, and health science, have also contributed to studying the digital divide.

Aiming to fill the conceptual and theoretical gap within digital divide research, van Dijk (2005) formulated the resource and appropriation theory. Nevertheless, as Pick and Sarkar (2016) indicated, several other theories and frameworks have been adapted to elucidate the digital divide, such as Rogers' (2003) innovation diffusion theory, the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003), Sen's (1999) capability approach, Regneda's (2017) stratification perspective in the digital era based on Weber's ideas, and Regneda's (2017, 2018) incorporation of Bourdieu's concept of capital to define digital capital.

The exploration of the digital divide has benefited from a multifaceted methodological landscape. Quantitative frameworks, including surveys, statistical analyses, and econometric models (Gounopoulos et al., 2018; Lengsfeld, 2011; Ojiako et al., 2019), have played a pivotal role in uncovering patterns and correlations that impact digital inclusion. Such approaches are invaluable for large-scale data scrutiny and for drawing generalisable conclusions. Conversely, qualitative methods, ranging from case studies and interviews to ethnographic inquiries (Carlo & Bonifacio, 2021; Ferreira et al., 2017; Tsatsou, 2008), infuse the discourse with rich contextual detail, revealing the lived experiences behind digital inequality.

Bibliometric studies are another vital research strand within this broad methodological framework. Basit et al. (2021) and Barik (2023) are among the few studies to have employed bibliometric techniques in this area. They utilised bibliometric techniques to conduct performance analysis, probing key aspects such as publication counts, citation metrics, and collaboration patterns through Web of Science data. Complementing this, Wang et al. (2022) focused their bibliometric analysis on co-citation and co-word patterns, explicitly examining the digital divide among the elderly population. These bibliometric studies highlight the diversity of analytical approaches and pinpoint specific thematic areas, thereby enriching our understanding of the digital divide.

The confluence of these diverse methodological approaches, from quantitative and qualitative to bibliometric analyses, has produced a nuanced, multifaceted understanding of the digital divide. As we navigate the ever-evolving digital terrain, continually refining and integrating these methods will be instrumental in informing effective policy interventions and capturing the dynamic nature of digital inequality.

2.2.4. Global Perspectives on the Digital Divide: Expanding the Horizon

In addition to European research on the digital divide, it is essential to acknowledge insights from global perspectives to develop a broader understanding of the subject. Research conducted in various regions offers valuable findings and diverse approaches that can enhance our comprehension of the digital divide's dynamics and consequences in the global context.

For example, research in the United States by scholars like DiMaggio and Hargittai (2001) addressed the implications of the internet in society, Jackson et al. (2008)and Sanders and Scanlon (2021) have given evidence of the effects of digital inequalities on race and gender, and Gonzalez (2016) has revealed that patterns of technology usage among different states are linked to socioeconomic variables and cultural settings.

In Asia, studies by Wen et al. (2023), Rajam et al. (2021), and Chetty et al. (2018) have examined the digital divide from the perspective of emerging economies, highlighting the importance of government policies and institutional frameworks. These studies emphasise the importance of providing suitable infrastructure, affordable access, and educational programs to promote inclusive digital adoption among individuals and businesses.

Furthermore, African scholars such as Mutula (2010), Yina (2020), and Aruleba (2022) have investigated the impact of the digital divide on individuals in the context of developing countries. They highlight the importance of digital literacy initiatives, community-driven endeavours, and partnerships between governments, private sectors, and international organisations to address digital inequalities effectively.

These diverse perspectives provide valuable insights into the multifaceted nature of the digital divide and can inform future research and policy recommendations in both European and global contexts.

2.2.5. The Firm-level Digital Divide: An Underexplored Dimension

While the extensive body of research has predominantly addressed the digital divide from an individual perspective, it is crucial to consider its implications at the firm level. The firm-level digital divide refers to the disparities in the capabilities to access, use, and adopt digital technologies among businesses, which can impact their competitiveness, productivity, and innovation (Ancillai et al., 2023; Calvino et al., 2022; Cirera et al., 2022; Scuotto et al., 2021; Shakina et al., 2021). Such disparities may lead to firms falling behind, ultimately affecting overall economic growth and intensifying income inequalities between businesses. Various factors can contribute to these disparities, including firm size, industry sector, geographical location, and the availability of financial and human resources (Bach et al., 2013; Torrent-Sellens et al., 2022). For instance, small and medium-sized enterprises (SMEs) in rural areas may face more significant challenges accessing high-speed internet and attracting skilled digital talent than large corporations in urban centres.

Examining the firm-level digital divide is crucial. It reveals the potential consequences of digital inequalities on the broader economic landscape and market dynamics, including the risk of hindered economic growth and exacerbated income disparities. In the European context, studies by Tylor and Murphy (2004), Plinskin et al. (2006), Wielicki and Arendt (2010), and Lehner and Sundby (2018) emphasise the differences in adopting and utilising ICT technologies and e-commerce between SMEs and large corporations. These regional and cross-national European comparisons highlight the significance of understanding the firm-level digital divide and its implications for businesses of varying sizes and industries.

In the context of European research, the literature addressing the digital divide at an industry level is relatively limited, prompting calls from scholars such as Bach et al.(2013), Cirera et al. (2022) and Shakina et al. (2021) for a more comprehensive analysis. Furthermore, studies such as Souza et al. (2017) provided empirical insights into the Brazilian scenario, emphasising the connection between access quality, digital expertise, and the extent of ICT tool usage among companies. Meanwhile, Chen et al. (2022) explore the Chinese landscape, revealing that the impact of the digital divide varies across distinct industry sectors, indicating the need for further analysis.

In addition to scholarship that explicitly addresses the digital divide, related insights can be found in the economics of ICT adoption and productivity literature. This stream investigates firm-level heterogeneity in the uptake and effective use of digital technologies, often focusing on organisational and managerial determinants. For example, Bloom et al. (2012) show that U.S. firms were able to extract higher productivity returns from IT than their European counterparts due to stronger managerial practices, illustrating that access to technology alone does not guarantee effective usage. Similarly, Fabiani et al. (2005) provide firm-level evidence from Italian manufacturing, demonstrating that adoption decisions are strongly influenced by firm size, human capital, and organisational change, while Schivardi and Schmitz (2022) highlight how weaker management capabilities in Southern Europe constrained the region's ability to benefit from the IT revolution. Although these studies do not employ the terminology of the digital divide, their findings align with its key constructs of access, skills, and usage, and underscore the role of complementary organisational and institutional factors in shaping digital disparities. Recognising these intersections reinforces the importance of further research that bridges digital divide scholarship with the broader literature on ICT adoption and productivity.

In order to address the firm-level digital divide effectively, policy interventions should consider tailored strategies, such as targeted digital infrastructure investments, skill development programs for SMEs, and public-private partnerships to promote digital adoption across different sectors (Saka et al., 2022; Torrent-Sellens et al., 2022).

In conclusion, this literature review has provided an exhaustive overview of the digital divide, highlighting its multifaceted nature and the various dimensions contributing to digital inequalities. By examining the historical development, theoretical frameworks, methodologies, and global perspectives on the digital divide, we have identified areas where further research is necessary, particularly in the context of the firm-level digital divide.

While significant progress has been made in understanding the digital divide, gaps in the literature still need to be addressed, particularly in studying the firm-level digital divide and its impact on businesses and the economy. Future research should delve deeper into the determinants and consequences of the firm-level digital divide, identifying effective strategies to bridge these gaps and foster a more equitable and competitive digital economy.

2.3. Methodology

Bibliometric analysis, as discussed in the literature, is a methodology that applies quantitative techniques to bibliographic data for assessing the impact and development of scientific publications and different research constituents by analysing citation data and other publication-related metrics (Aria & Cuccurullo, 2017; Cobo et al., 2011; Donthu et al., 2021; Ellegaard, 2018). According to Nakagawa et al. (2019) and Donthu et al. (2021), bibliometrics allows researchers to uncover emerging trends, identify knowledge gaps in specific domains, and analyse large quantities of publications.

This study employs a comprehensive bibliometric analysis, grounded in the framework proposed by Donthu et al. (2021), to analyse the dynamic landscape of digital divide research. The analysis unfolds in performance analysis, science mapping, and network analysis. Performance analysis provides a descriptive overview of the field, quantifying the number of publications and citations associated with various research components (Donthu et al., 2021; Nakagawa et al., 2019). Moreover, the study incorporates science mapping techniques involving citation analysis and similarity metrics like co-citation and bibliographic coupling. Co-citation analysis serves to identify the intellectual core of the field. Figure 3 illustrates how two publications, A and B, are co-cited by a third one, C, indicating that they share conceptual or thematic affinities. This cluster constitutes the field's "knowledge base." Conversely, bibliographic coupling highlights the "research front," representing emergent and active investigation areas. Figure 3 shows how two publications, A and B, are bibliographically coupled by a third reference, C, suggesting that both academic publications address emerging active research areas and share similar unsolved research problems (Boyack & Klavans, 2010; Kammerer et al., 2021).

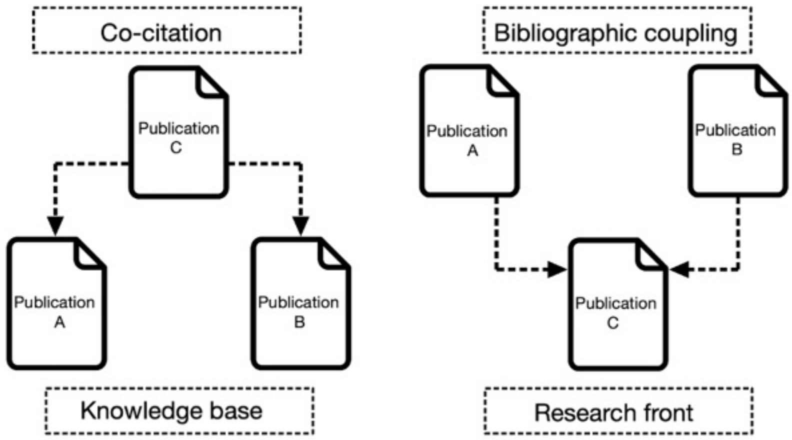

Figure 3: Co-citation and Bibliographic Coupling.

Source: Kammerer et al., 2021.

Network analysis further enhances this approach that utilises both network and node-level metrics. At the network level, connectivity within the research community is measured by network density, which sheds light on the extent of collaboration or shared knowledge (Wasserman & Faust, 1994). Modularity measures the strength of network division into clusters, making it easier to identify research communities that frequently cite each other or work on similar topics (Newman, 2006). The clustering coefficient reveals the interconnectedness of publications within a cluster, indicating the potential for knowledge diffusion within those groups (Watts & Strogatz, 1998).

In order to produce the most compelling description of a network, a combination of the Fruchterman-Reingold algorithm and the Louvain method for community detection or clustering is employed. These techniques allow for a more optimal and easy interpretation of the network visualisation, which aligns with the aforementioned specific metrics.

At the node level, degree centrality (DegC) helps identify the most impactful publications in a particular field, measuring their recognition or influence (Freeman, 1978). PageRank centrality (PRC) takes this further by considering the number of connections a node has and the quality of those connections, providing a more nuanced understanding of influence within the scholarly community (Brin & Page, 1998).

By integrating performance analysis, science mapping techniques, and network analysis with both network and node-level metrics, this study aims to provide a multi-dimensional view of the digital divide literature. These comprehensive metrics assist in identifying influential works and understanding the field's intellectual structure, thereby highlighting its evolution and potential future directions.

2.3.1. Data Collection, Processing, and Cleaning

Caputo and Kargina (2022) and Echchakoui (2020) note that authors often rely on a single data source like Web of Science or Scopus for bibliometric analysis. When using both, they typically perform separate analyses. In contrast, Singh et al. (2021) emphasise the extensive coverage of scientific journals and publications within Web of Science, Scopus, and Dimensions databases. This study will merge data from all three databases to capitalise on these comprehensive data sources for a more thorough and robust bibliometric analysis.

The selection strategy of this study was designed to capture scholarship that explicitly engages with the concept of the *digital divide*. To this end, the analysis includes authors with European affiliations and publications across sociology, economics, administration, computer science, and technology, and applies a focused search equation ("digital divide*" OR "digital inequalit*" OR "digital gap*") to filter publications by titles and author keywords. Several preprocessing and cleaning steps were undertaken to guarantee data quality and consistency, which is essential for the robust implementation of the selection strategy. This search design was intentionally narrow in order to map the intellectual structure and evolution of a research community that self-identifies with the digital divide and frames digital disparities in those terms. Broadening the query to include related terms would have incorporated other streams of literature, such as the diffusion of innovations and productivity studies, which represent a more mature body of work and investigate closely related phenomena under labels like heterogeneous ICT adoption, incomplete diffusion, or productivity asymmetries. While conceptually complementary, including this literature would have blended distinct intellectual communities and risked obscuring the knowledge base, citation structures, and research fronts specific to the digital divide. The present bibliometric analysis focuses on the digital divide discourse to uncover its internal intellectual structure, identify specific gaps, and examine its intersections with related literatures. This lays the foundation for future research that can more clearly link these strands.

First, duplicates across Web of Science, Scopus, and Dimensions were identified and eliminated, ensuring each document was unique in the final dataset. Second, data normalisation and consolidation were applied to author names, affiliations, and keywords. This process involved correcting spelling, abbreviations, and capitalisation variations and identifying and merging records that referred to the same author, institution, or keywords.

After thorough data processing and cleaning, an analysis of 1,609 unique documents published between 2000 and 2022 was performed. The data were categorised into three periods: P1 (2000-2007), P2 (2008-2015), and P3 (2016-2022), as well as the total period, TP (2000-2022). This categorisation facilitates fair comparisons, allows monitoring of the evolution of digital divide literature, and allows pinpointing emerging trends.

The potential limitation of the data collection process lies in the possibility of overlooking relevant studies not indexed in the selected databases. Nonetheless, the dataset is considered to provide a comprehensive representation of the digital divide research landscape and its associated trends. Furthermore, to ensure replicability and reproducibility, this research includes a public GitHub repository called "dd_bibliometric_europe," which contains the data management plan, cleaning, and processing using the R programming language environment with bibliometrix and igraph packages.

2.4. Results

In this section, the results of the bibliometric analysis are presented, addressing the research questions and objectives outlined earlier. The findings are organised into three parts: first, a performance analysis of various research constituents (publications, authors, journals, universities, and countries). Second, science mapping encompasses citation analysis, as well as the integration of co-citation and bibliographic coupling with network analysis, and finally, the interpretation of the results.

2.4.1. Performance analysis

Following Abramo and D'Angelo (2014) and Wang and Barabási (2021), performance analysis measures productivity (number of publications) and impact (number of citations). Examining Table 2, in conjunction with Figure 4, allows for a deeper insight into the dynamics and trends within the digital divide research landscape during the timeframes of P1, P2, P3, and TP. During the total period TP, the annual growth rate of publications is 26.69%, with an average of 18.74 citations per document.

Details	P1	P2	P3	TP
Timespan	2000 - 2007	2008 - 2015	2016 - 2022	2000 - 2022
Journals	123	284	530	832
Annual growth rate	71,14	3,74	15,67	26,69
Average citations per document	42,87	24,27	10,36	18,74
Articles	159	348	743	1250
Book chapters	4	34	17	55
Proceedings and conference papers	39	115	150	304
Total published documents	**202**	**497**	**910**	**1609**

Table 2: Comparative Summary of Document Types and Measures.

Source: Author's elaboration.

The analysis included 1,609 documents published in 832 journals by 3,506 authors, totalling 38,932 cited references. Despite the fluctuations in citation patterns, the topic of the digital divide has gained significant attention within the scientific community in Europe, showcasing its growing relevance in today's increasingly digital world. In P1, 202 unique documents were written by 370 authors and published in 123 scientific journals. Despite the annual growth rate of publications and the average number of citations per document in P1 being 71.14% and 42.87, respectively, a significant decline occurred in P2, with these values dropping to 3.74% and 24.27, respectively. In P2, the total number of publications reached 497, involving 1009 authors and published across 284 journals. However, During P3, the number of publications rebounded to 910, involving 2285 authors and appearing across 530 scientific journals. In this last period, P3, the annual growth rate recovered to 15.67%, while the average citations per document decreased to 10.36.

It is crucial to consider various factors that may contribute to reducing average citations per document in Figure 4 (Right). Firstly, recent publications require more time to accumulate citations. Secondly, as the digital divide expands in publications, citations may be dispersed across more documents, resulting in a decline in average citations per document. Finally, the digital divide is a multidisciplinary topic, and research in this field may have become more specialised, prompting researchers to concentrate on narrower aspects of the digital divide.

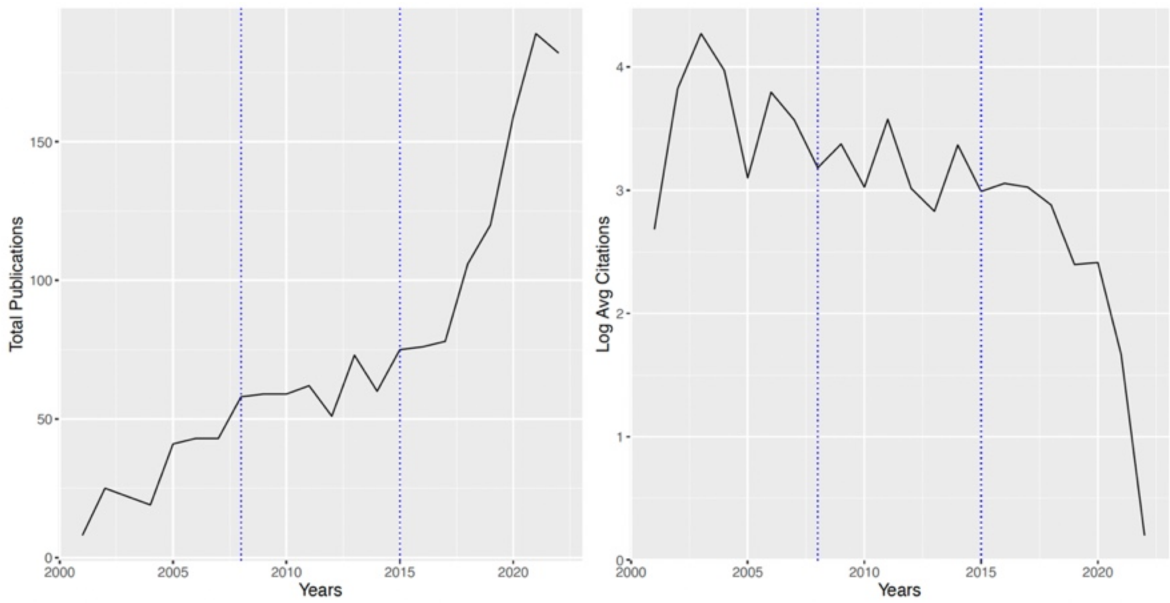

Figure 4: (Left) Total publications per year. (Right) Relative change in the average citation per year. Source: Author's elaboration.

In summary, the productivity and impact figures unveil significant trends and variations. Table 1 and Figure 4(Left) show that researchers' interest in the digital divide has steadily increased, highlighting its growing importance in today's rapidly advancing digital society. Acknowledging the decline in average citations per document during P3 in Figure 4(Right) is important. However, the general trend across the periods highlights that the field of digital divide research remains highly relevant and constantly developing. Therefore, it is crucial to emphasise the need for ongoing investigation and examination in this domain as new digital technologies continue to evolve and expand.

2.4.1.1. Authors

In this section, the authors' performance is presented. As shown in Figure 5, James J. emerges as the most productive author with 25 publications, followed by van Deursen A. with 24, and van Dijk J. with 18 publications. The legend in the figure indicates that dot size represents the number of publications, while the colour intensity reflects the times cited per year. In terms of scholarly influence, as measured by citation counts, van Dijk J. ranks first with 3,644 citations. He is followed by van Deursen J. with 2,515 citations, and Hargittai E. with 775 citations.

This comparison uncovers a nuanced landscape in digital divide research, where productivity and impact do not always align. High publication counts do not necessarily lead to greater academic influence, and vice versa. This highlights the importance of adopting a multidimensional approach when evaluating scholarly contributions, balancing quantitative outputs with citation-based influence.

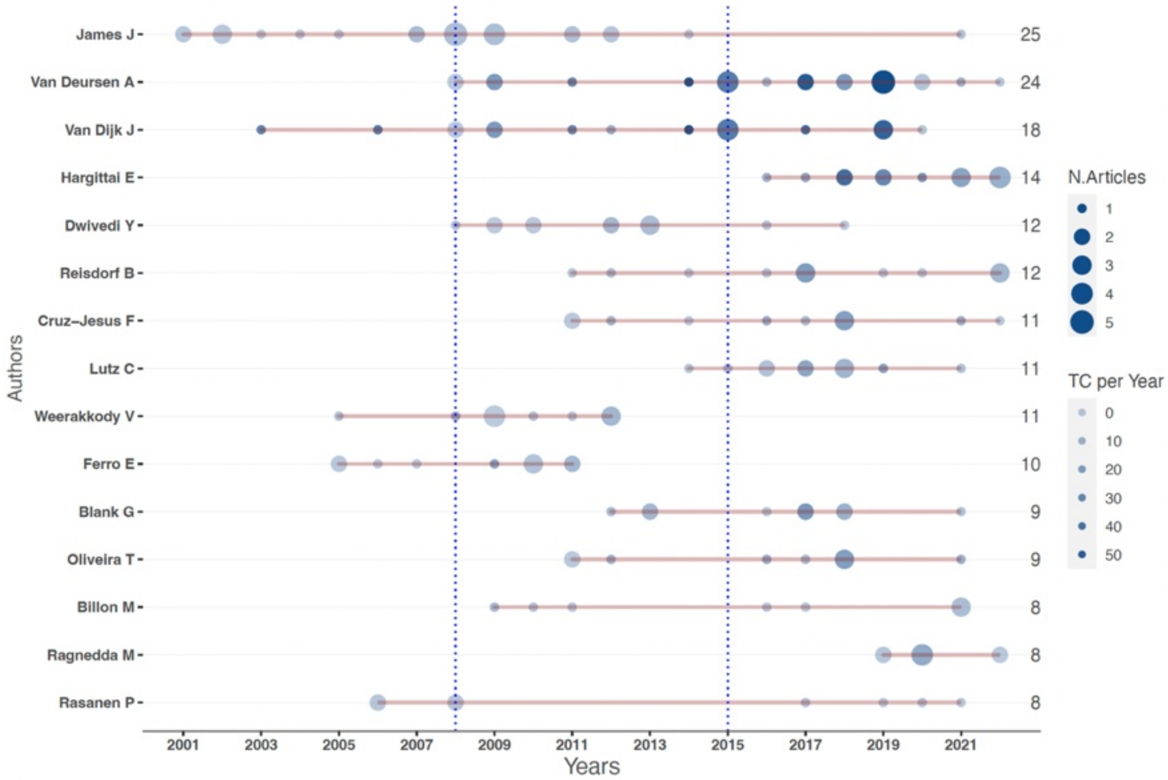

Figure 5: Top 15 of Authors' publication patterns over time. TC: Times Cited.

Source: Author's elaboration.

Moreover, the presence of authors with fewer publications yet notable citation densities suggests the potential emergence of influential voices and novel research trajectories. These scholars may be spearheading shifts in the theoretical or methodological direction of the field, indicating a dynamic and evolving research landscape that merits further exploration.

2.4.1.2. Publications

Table 3 illustrates a ranking of the most influential articles based on the highest number of citations for P1, P2, and P3. For P1, the article The Digital Divide As A Complex And Dynamic Phenomenon (Jan. van Dijk & Hacker, 2003) was cited 664 times. The second most cited article was Digital Divide Research, Achievements, and Shortcomings (Jan. van Dijk, 2006). These two articles contend that digital inequalities encompass more than just physical access, providing a comparative analysis of various access types, including physical, skill-based, and usage access, among diverse demographic groups in the United States and the Netherlands. Furthermore, the authors highlighted the gaps in digital divide research, emphasising the need for theoretical development, interdisciplinary collaboration, and conceptual refinement.

Rank	Article	TC
P1: 2000 - 2007		
1	Van Dijk J; Hacker K (2003) - The Digital Divide As A Complex And Dynamic Phenomenon	664
2	Van Dijk J (2006) - Digital Divide Research, Achievements And Shortcomings	660
3	Livingstone S; Helsper E (2007) - Gradations In Digital Inclusion: Children, Young People And The Digital Divide	587
4	Selwyn N (2004) - Reconsidering Political And Popular Understandings Of The Digital Divide	560
5	Introna l; Nissenbaum H (2000) - Shaping The Web: Why The Politics Of Search Engines Matters	463
P2: 2008 - 2015		
1	Van Deursen A; Van Dijk J (2014) - The Digital Divide Shifts To Differences In Usage	555
2	Van Deursen A; Van Dijk J (2011) - Internet Skills And The Digital Divide	402
3	Becker S; Miron-Shatz T; Schumacher N; Krocza J; Diamantidis C; Albrecht U (2014) - Mhealth 2.0: Experiences, Possibilities, And Perspectives	289
4	Helbig N; Gil-García J; Ferro E (2009) - Understanding The Complexity Of Electronic Government: Implications From The Digital Divide Literature	268
5	Carter L; Weerakkody V (2008) - E-Government Adoption: A Cultural Comparison	208
P3: 2016 - 2022		
1	Iivari N; Sharma S; Ventä-Olkkonen L (2020) - Digital Transformation Of Everyday Life – How Covid-19 Pandemic Transformed The Basic Education Of The Young Generation And Why Information Management Research Should Care?	386
2	Friemel T (2016) - The Digital Divide Has Grown Old: Determinants Of A Digital Divide Among Seniors	347
3	Scheerder A; Van Deursen A; Van Dijk J (2017) - Determinants Of Internet Skills, Uses And Outcomes. A Systematic Review Of The Second- And Third-Level Digital Divide	307
4	Hunsaker A; Hargittai E (2018) - A Review Of Internet Use Among Older Adults	223
5	Van Deursen A; Van Dijk J (2019) - The First-Level Digital Divide Shifts From Inequalities In Physical Access To Inequalities In Material Access	198

Table 3: Top Five Most-Cited Articles per Time Period, indicated by the Number of Times Cited (TC). Source: Author's Elaboration.

In P2, the most influential article is titled The Digital Divide Shifts To Differences In Usage (van Deursen & van Dijk, 2014), with 555 citations, followed by Internet Skills And The Digital Divide (van Deursen & van Dijk, 2011), which garnered 402 citations. These articles emphasise the shift in focus from access disparities to the differences in how individuals use the internet. They delve into the various aspects of internet skills and how they contribute to the widening digital divide. By examining the usage patterns and skill sets of different demographic groups, the authors shed light on the evolving nature of the digital divide and the need for targeted interventions to bridge these gaps.

During P3, the article Digital Transformation Of Everyday Life – How Covid-19 Pandemic Transformed The Basic Education Of The Young Generation And Why Information Management Research Should Care? by Livari et al. (2020) garnered 386 citations, while The Digital Divide Has Grown Old: Determinants Of A Digital Divide Among Seniors by Friemel (2016) received 347 citations. The former article by Livari et al. (2020) highlights the extensive digital transformation in society and primary education for children due to the COVID-19 pandemic, revealing digital divides and stressing the need for information management research to address challenges students, teachers, and families face in adapting to the new normalcy. While Friemel (2016), on the other hand, explores the "grey divide" in Internet use among seniors aged 65+ years, revealing a partial exclusion of older seniors (70+) and highlighting the importance of education, income, technical interest, pre-retirement computer use, and social context in predicting Internet use among this age group.

2.4.1.3. Journals

High-impact journals play a pivotal role in shaping the scholarly discourse on the digital divide. Figure 6 shows that *New Media & Society* is the most influential scientific journal, accumulating 4,427 citations and 42 publications. Following closely as the second most influential journal is *Information Society*, with 2,066 citations and 26 publications.

Information Communication & Society also shows strong performance, with 43 publications and 1,165 citations. Notably, although *Poetics* and the *European Journal of Communication* have fewer publications, the articles they host make meaningful contributions to the field.

Most of the journals listed in this analysis hold a Q1 ranking, underscoring their prominence within the academic landscape. An exception is *Universal Access in the Information Society*, which is ranked Q2.

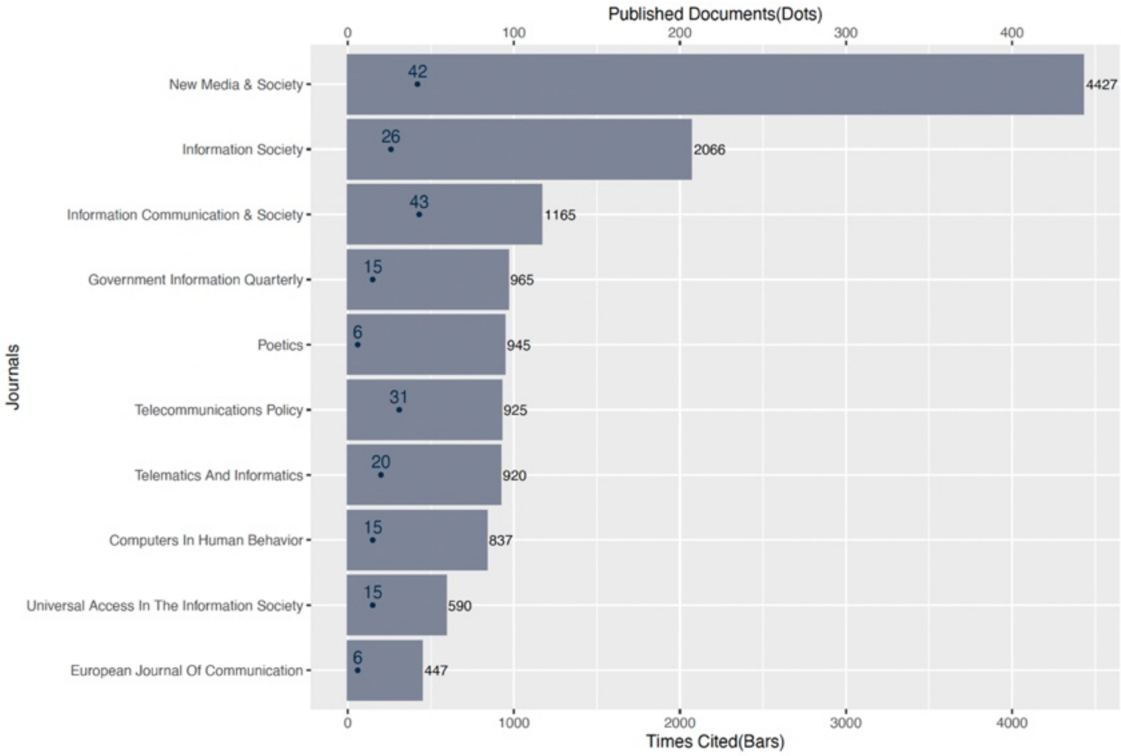

Figure 6: Top 10 Journals' Performance 2000-2022.

Source: Author's elaboration.

This distribution suggests that while a few flagship journals, such as *New Media & Society* and *Information Society*, dominate both in terms of output and citations, meaningful contributions are also emerging from journals with lower volume but high-quality content. The presence of Q1-ranked journals across diverse communication and policy domains reflects the interdisciplinary nature of digital divide research. Meanwhile, the Q2 ranking of *Universal Access in the Information Society*, despite its niche focus, indicates that visibility and impact are not solely driven by quartile rank but also by thematic relevance.

2.4.1.4. Universities

Figure 7 highlights the major institutional contributors to digital divide research. The University of Twente in the Netherlands leads with 4,085 citations across 31 publications, followed by the London School of Economics, which recorded 2,195 citations and 24 publications. Other prominent European institutions include the University of Zurich (1,581 citations) and the University of Oxford (1,037 citations).

While most contributions stem from authors affiliated with European institutions, it is important to recognise the role of international collaboration. Research output often reflects joint efforts across affiliations, shaping unique patterns of scholarly cooperation. For instance, New Mexico State University appears in the top ten despite having only one publication, van Dijk and Hacker's (2003) highly cited article with 664 citations. This highlights the impact that collaborative and foundational publications can have on the field.

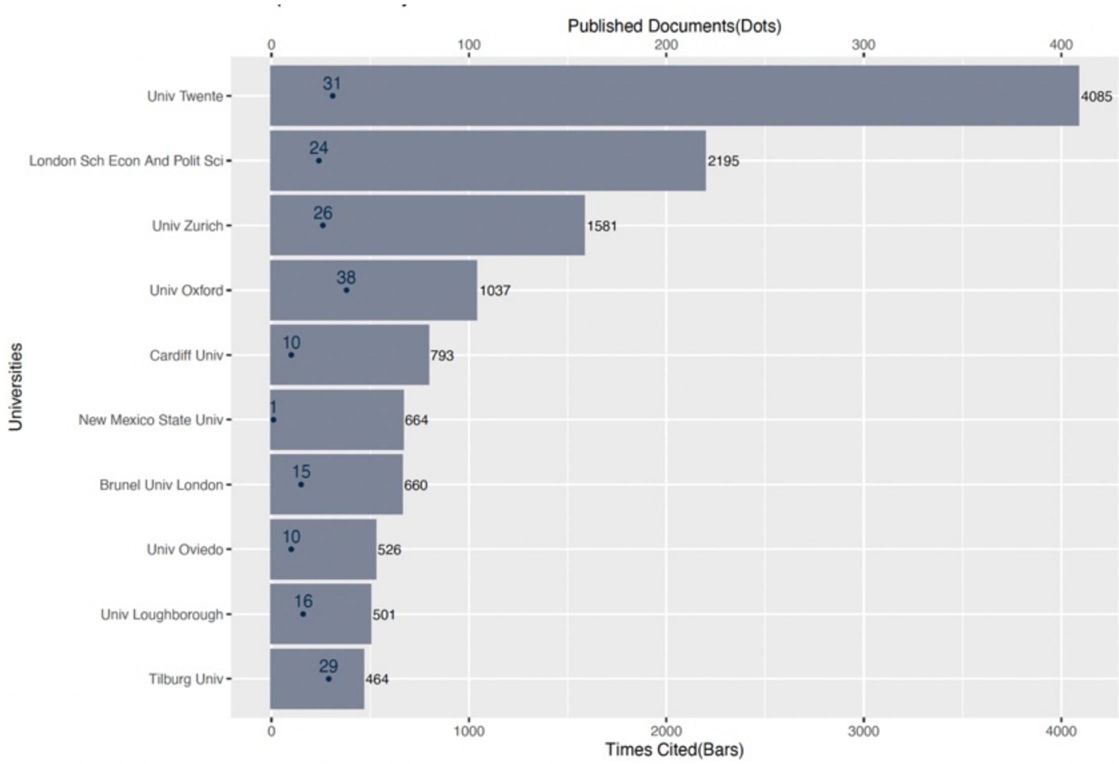

Figure 7: Top 10 universities' performance 2000-2022.
Source: Authors' elaboration.

2.4.1.5. Countries

This section discusses the top ten most productive and influential countries in digital divide research, as illustrated in Figure 8. The United Kingdom (UK) leads the field with 10,689 citations and 384 publications, followed by the Netherlands in second place, having accumulated 5,415 citations across 109 publications.

The United States (US) occupies the third position in terms of influence. Although this analysis primarily focuses on European countries, it is essential to note that several European nations (see Figure 9) have not only collaborated with the US but also with other countries on various research initiatives. This observation highlights the importance of international colaboration in driving research endeavours within the field of digital divide studies.

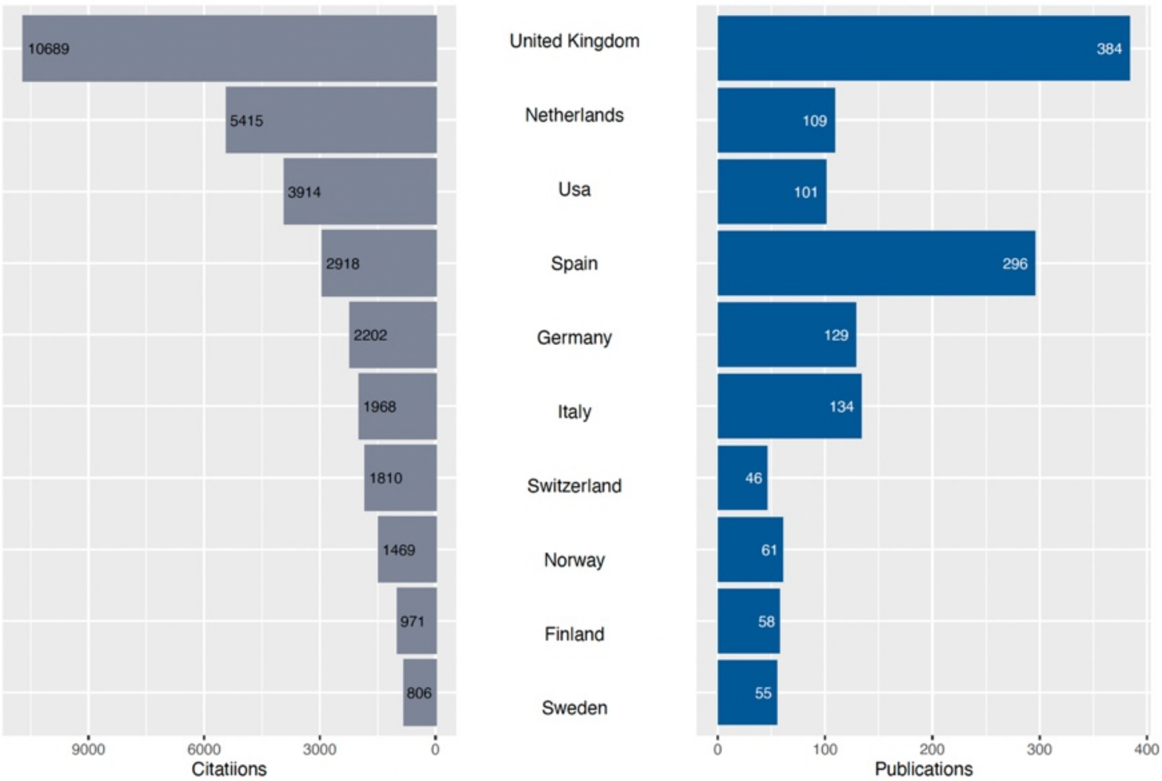

Figure 8: Top 10 countries' performance 2000-2022.

Source: Authors' elaboration.

According to Figure 9 and the information provided in Table A.1, the collaboration network among countries is moderately dense, with a density of 0.337. This means that the participating countries are relatively interconnected. The network also tends to form distinct clusters, as indicated by the modularity of 0.495. However, these clusters are nearly well-connected internally, with a cluster coefficient of 0.581. Lastly, the network comprises three main clusters, each with its hub of academic influence in digital divide research.

In Cluster 1, the United Kingdom (UK) stands out as the leading player with the highest DegC and PRC values, as shown in Table A.2. The USA also plays a significant role in this cluster with a solid connection to the UK. The Netherlands, Belgium, Canada, Ireland and other countries are also collaborating in this cluster, revolving around the UK and contributing to its position as the centre of digital divide research in this group.

Cluster 2 exhibits a different dynamic, where countries like Spain and Germany take the lead in terms of both DegC and PRC. They act as central nodes around which other countries in the cluster revolve. In contrast, Cluster 3 lacks a robust and centralised influence, with Italy showing the highest DegC and PRC values, yet with a more scattered arrangement of countries regarding collaborative partnerships.

In summary, the network metrics and topological features underline the United Kingdom's pivotal role in shaping the discourse in European research on the digital divide while highlighting the regional clusters and diverse collaborative relationships among different countries.

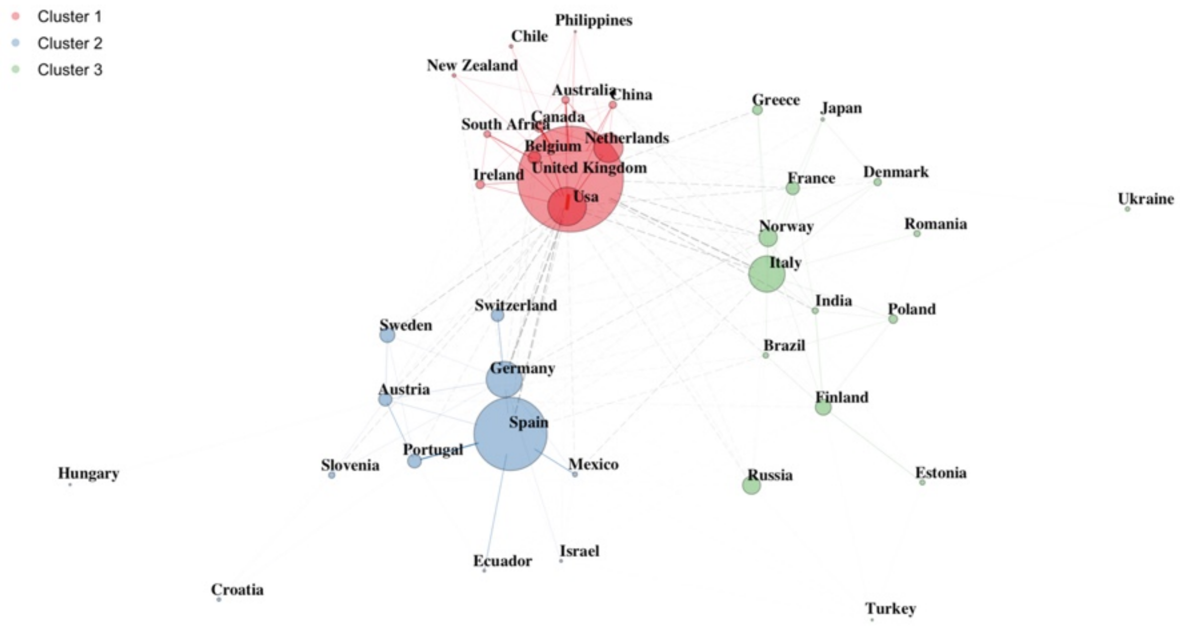

Figure 9: Country Collaboration Network.
Source: Authors' elaboration.

2.4.2. Science Mapping and Network Analysis

Considering the complex web formed by co-citation and bibliographic coupling networks, adopting a focused approach for visualisation becomes imperative. The use of degree of centrality as a criterion for isolating specific nodes is well-supported in the literature. Saxena and Iyengar (2020) and Imamverdiyev et al. (2010) advocate for utilising the degree of centrality measure to identify nodes with a high volume of connections, thereby aiding in the simplification of network visualisation and facilitating the interpretation of its core structure (Blagus et al., 2015; Rafiei, 2005) .

Guided by these principles, the present analysis isolates the 30 nodes marked by the highest degree of centrality to refine the network's complexity without diminishing its analytical depth. While this focused approach offers invaluable insights into pivotal publications and key relational dynamics, it may introduce a particular bias by giving prominence to well-established nodes, potentially overlooking emerging but less connected publications. Nevertheless, this methodological decision has been made to maintain a balance between comprehensibility and analytical depth. At the same time, to simplify the readability and facilitate identification within these visual networks, each vertex represents a publication, labelled by the first author's last name and the year of publication. For a complete list of articles corresponding to each vertex, please refer to the Appendix A.

The robustness of the findings remains generally uncompromised, rendered in a more accessible and actionable manner. A comprehensive exposition of the metrics resulting from this approach will be provided in Appendix A. While the metrics themselves are reserved for the appendix, the interpretative implications of these findings will set the stage for Sections 4.2.2 and 4.2.3. These subsequent sections will specifically delve into the nuanced interpretation of co-citation analysis and bibliographic coupling. To further enhance the interpretative richness of the analysis, each network will feature a word cloud for each constructed cluster. These word clouds are generated from the most frequent terms found in the abstracts of the cited publications after excluding stop words and high-frequency terms (i.e., digital divide, technology...). This additional layer allows for a nuanced interpretation of the clusters and network topics, thereby contributing to a dynamic mapping of the evolution of the digital divide in the academic literature.

2.4.2.1. Citation Analysis

Table 4 presents the most cited references within the digital divide domain, signifying the most influential works and representing the knowledge base in this area. The analysis of Table 4 suggests that these seminal works have introduced groundbreaking theoretical frameworks, methodologies, and key concepts that contribute to our understanding of the digital divide. In subsequent sections, a co-citation network will provide a more comprehensive visualisation of the knowledge base.

Rank	Article	TC
1	Norris P (2001) -Digital Divide Civic Engagement, Information Poverty, and the Internet Worldwide	204
2	Van Dijk J (2005) -The Deepening Divide: Inequality in The Information Society	172
3	Hargittai E (2002) -Second-Level Digital Divide: Differences in People's Online Skills	136
4	Van Dijk J (2006) -Digital Divide Research, Achievements and Shortcomings	129
5	Van Dijk J, Hacker K (2003) -The Digital Divide as A Complex and Dynamic Phenomenon	114
6	Selwyn N (2004) -Reconsidering Political and Popular Understandings of The Digital Divide	108

7	Dimaggio P, Hargittai E, Celeste C, Shafer S (2004) -From Unequal Access to Differentiated Use: A Literature Review and Agenda for Research on Digital Inequality	105
8	Van Deursen A, Van Dijk J (2014) -The Digital Divide Shifts to Differences In Usage	103
9	Zillien N, Hargittai E (2009) -Digital Distinction: Status-Specific Types of Internet Usage	82
10	Hargittai E, Hinnant A (2008) -Digital Inequality: Differences in Young Adults' Use Of The Internet	80

Table 4: Top 10 Most Cited References 2000- 2022. TC: Times Cited.

Source: Author's Elaboration.

2.4.2.2. Co-citation analysis

Figure 10 displays a simplified version of the co-citation network that covers the period from 2000 to 2007. This network is composed of three distinct clusters. Table A.3 shows a density of 0.634, modularity of 0.467, and a cluster coefficient of 0.766. These metrics collectively suggest a tightly-knit but modular intellectual landscape, indicative of cohesive clusters with significant internal interconnectedness. Within this structural framework, publications can be distinguished into dominant and peripheral categories based on their centrality measures.

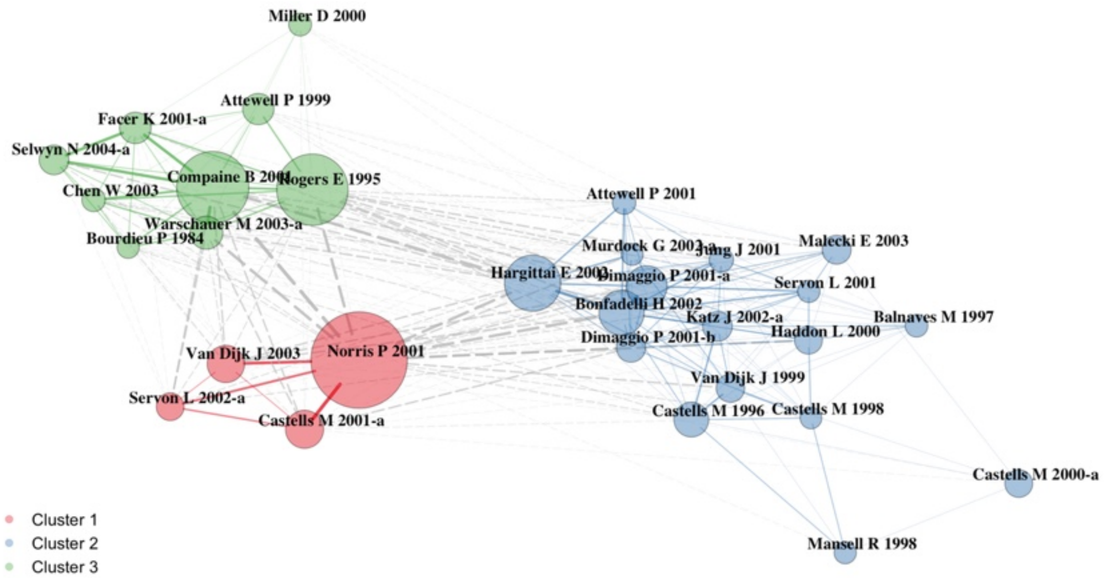

Figure 10: Co-Citation Network 2000-2007.

Source: Authors' elaboration.

Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

Larger nodes identify dominant publications with higher metrics like degree of centrality (DegC), serving as focal points around which the scholarly discussion revolves. The works that act as central nodes in shaping fundamental frameworks, methodologies, and thematic directions include Norris (2001) in Cluster 1, Hargittai (2002) in Cluster 2, and Compaine

(2001) and Rogers (1995) in Cluster 3. Their high DegC implies frequent co-citation with other works, thereby wielding considerable influence on the discourse within their respective clusters. Detailed metrics for these central nodes can be found in Table A.4.

In contrast, peripheral publications still play a pivotal role despite exhibiting lower centrality measures. They contribute to the domain by elaborating on and refining the foundational ideas posited by dominant publications and occasionally introducing fresh perspectives into adjacent areas in the domain of the digital divide.

Examining the PageRank centrality (PRC) metrics provides deeper insight into the influential works within the network. Key nodes worthy of attention include Norris (2001) from Cluster 1, Bonfadelli (2002) and Hargittai (2002) from Cluster 2, as well as Compaine (2001) and Dimaggio and Hargittai (2001) from Clusters 2 and 3, respectively. These publications have high connections and strategic links to other highly cited works, confirming their importance in shaping academic discussions.

The word clouds depicted in Figure 11 provide an insightful thematic illustration for each cluster, revealing distinct thematic patterns that enrich our understanding of the scholarly discourse on the digital divide. Cluster 1 is notably concentrated on foundational issues of "Access," accentuated by sub-themes that include societal and economic aspects, such as age groups and national disparities. This cluster primarily anchors the discourse regarding societal structures and economic implications.

Figure 11: Thematic Word Clouds for Co-citation Clusters for 2000-2007.

Source: Author's elaboration.

Cluster 2, while also emphasising "access," incorporates a more nuanced lens by including terms related to individual skills and the concept of a "Network Society." It also introduces particular attention to rural contexts. It thus mediates the balance between foundational issues of access and emerging discussions around skill-based divides within varied socio-geographic settings. Cluster 3 presents an eclectic array of themes, including the impact of culture and a focus on specific demographic groups like children. Moreover, Rogers (1995) is highly co-cited in this cluster, suggesting that the digital divide literature incorporates theories such as the diffusion of innovations that look beyond mere access issues.

In Figure 12, the co-citation network for the period 2008-2015 demonstrates an even more tightly interconnected scholarly landscape compared to earlier years, as evidenced by network metrics in Table A.5, a density of 0.982 and a remarkably high cluster coefficient of 0.984. The modularity measure of 0.478 suggests that while the network is cohesive, distinct thematic clusters still exist, although more closely related than before. Notably, Cluster 3 is an exception, lacking dominant publications and remaining relatively isolated from the other two clusters, indicating a nascent or divergent area of research within the field of digital divide studies.

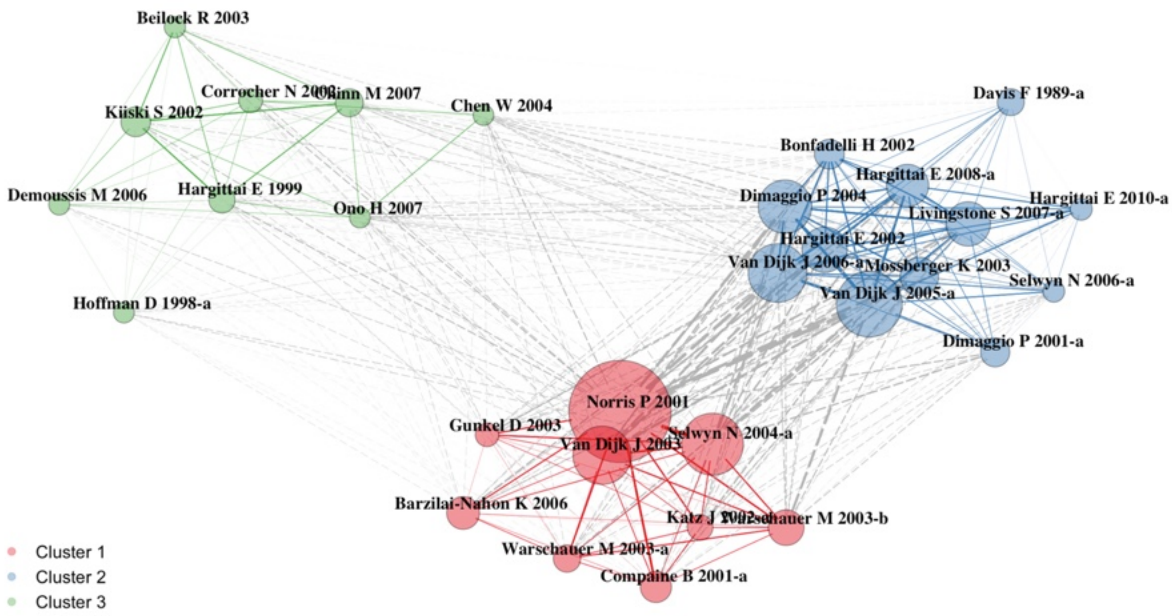

Figure 12: Co-Citation Network 2008-2015.

Source: Author's elaboration.

Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

Regarding individual publications serving as focal points in this network, Norris (2001) from Cluster 1 maintains a significant role, evidenced by the highest DegC as shown in Table A.6. Similarly, Selwyn (2004) from Cluster 1 and van Dijk (2005; 2006) from Cluster 2 stand out as intellectual anchors, shaping the themes of their respective clusters. Among these, van Dijk's 2005 work is particularly notable for formulating the Resources and Appropriation theory, a native theoretical framework within digital divide studies, thereby establishing it as a central actor with added weight in the scholarly discourse.

Complementing these key publications are those with the highest PRC, specifically Norris (2001) from Cluster 1 and van Dijk (2005) from Cluster 2, both of which are well-cited and closely linked to other significant studies in the field, which enhances their influence even further. Dimaggio et al., (2004) and Hargittai (2002), both from Cluster 2, further strengthen this landscape as secondary centres of influence, underscored by their high PRC scores. These dominant nodes with elevated DegC and PRC measures exert a substantive influence in steering the thematic directions of digital divide research during this period.

In Figure 13, the word cloud illustrates the themes of the second co-citation network for 2008-2015, revealing nuanced insights into the evolving contours of digital divide research. Cluster 1 emphasises issues related to the first-level digital divide, mainly focusing on access and its social implications. In this cluster, there is also a distinct academic shift toward measurement and the conceptualisation of ICT use among individuals, suggesting a maturing field underpinned by rigorous methodologies.

Figure 13: Thematic Word Clouds for Co-citation Clusters for 2008-2015.

Source: Author's elaboration.

Cluster 2, on the other hand, addresses the second-level digital divide by delving into skills and individual usage patterns. Its emphasis on specific demographics reflects a move toward a more granular examination of how the digital divide manifests across different age groups. In conclusion, Cluster 3 is unique because of its wide range of themes and focus on various geographical locations. This adds value to academic discussions by including perspectives from both American and African contexts, thereby giving a global perspective to the understanding of the digital divide.

In Figure 14, representing the co-citation network for 2016-2022, the intellectual landscape is highly dense, as demonstrated by the network density of 0.986 and a cluster coefficient of 0.986. These metrics presented in Table A.7 signal a tightly interconnected research field with distinct clusters that maintain unique thematic focuses, as indicated by a modularity score of 0.458. Publications in Cluster 1, most notably van Deursen and Helsper (2015), van Dijk and van Deursen (2014), and van Dijk (2005), emerge as central nodes with both high DegC and PRC scores as shown in Table A.8. Their dominant positions suggest an outsized influence on the discourse within their respective clusters and, by extension, the domain of the digital divide. Hargittai (2002) in Cluster 1 and Hargittai and Hinnant (2008) in Cluster 3 also serve as secondary but crucial centres of influence, evidenced by their high PRC scores.

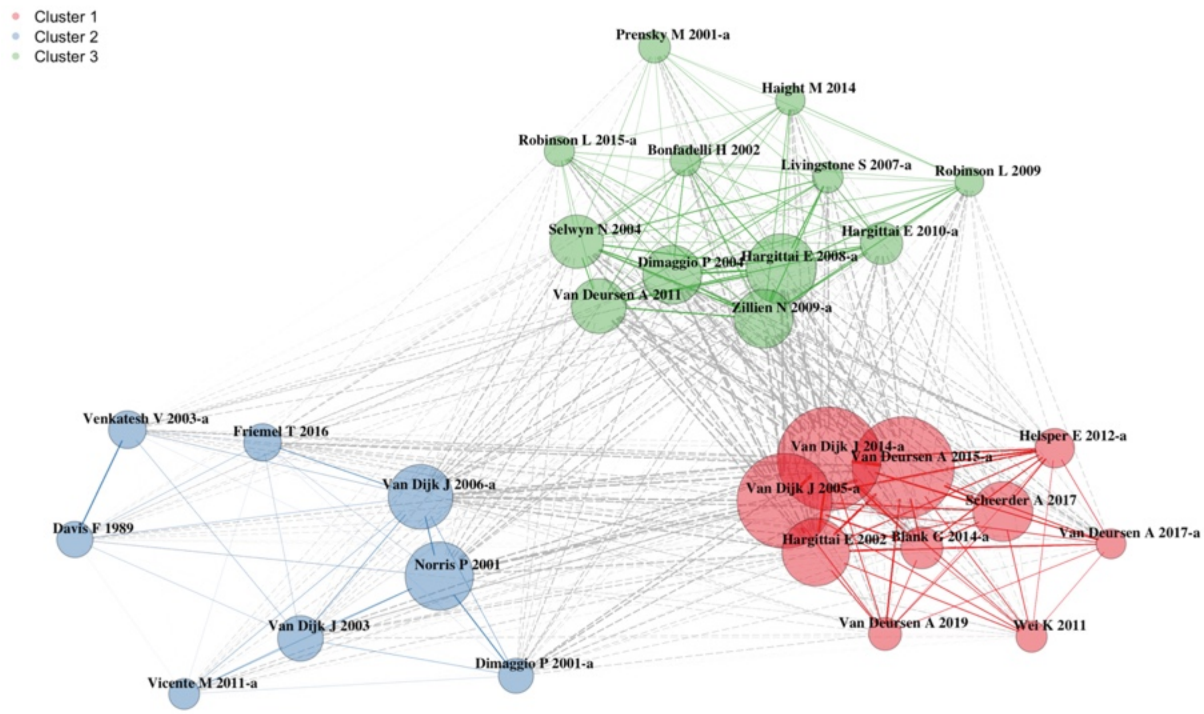

Figure 14: Co-Citation Network 2016-2022.

Source: Author's elaboration.

Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

In contrast, publications in Cluster 2, particularly Norris (2001) and van Dijk (2006) and van Dijk and Hacker (2003), exhibit high DegC but lack high PRC scores. Notably, Cluster 2 is also geographically distant from Clusters 1 and 3 in the network visualisation. This spatial and metric divergence suggests a diminishing focus on these works. While they were pivotal in shaping the discourse in earlier periods, their influence has weakened as the thematic focal points of the digital divide literature have evolved.

In Figure 15, the word cloud illustrates the evolution of thematic emphases in digital divide research, which becomes evident across the three clusters. Cluster 1 demonstrates an expanded scope, now explicitly addressing the third level of the digital divide by discussing the outcomes resulting from varied types of digital use. This shift represents an intellectual maturation, allowing for more complex explorations into how different modes of digital engagement yield diverse individual outcomes. Concurrently, mentioning specific platforms like Twitter signals a growing interest in how particular digital environments affect user experience and skills. Cluster 2 introduces a noteworthy emerging topic, geographical and regional contexts, as evidenced by its focus on regional perspectives like the Dutch setting. This emphasis indicates a shift towards a more globalised examination of digital divide issues, encompassing the influence of policy and location.

Figure 15: Thematic Word Clouds for Co-citation Clusters for 2016-2022.

Source: Author's elaboration.

Cluster 3, relatively distant from Clusters 1 and 2, showcases an array of interdisciplinary topics. This diverse focus includes age demographics, social network analysis, and status, offering a rich palette of approaches to the digital divide, from sociological to technological perspectives. This cluster thus stands as a testimony to the diversification and expansion of the digital divide discourse, enriching the field with various analytical lenses. Overall, the thematic transitions across these clusters mirror the evolving landscape of digital divide research and underscore its increasing complexity and global relevance.

The scholarly discourse on the digital divide has evolved substantially over the three periods under examination, revealing shifts in focus indicative of the field's development and the changing technological landscape. In the first period, from 2000 to 2007, the dialogue concentrated mainly on foundational elements like access, social factors, and economic implications, laying the groundwork for more nuanced discussions in later years. By the second period, 2008-2015, the conversation had advanced to include discussions of skills, individual usage, and rural vs urban dynamics, signalling a transition toward a more refined understanding of the second-level digital divide. In the third period, from 2016 to 2022, the thematic focus expanded to incorporate the third level of the digital divide, examining the varied outcomes of digital use and adding emerging topics like regional and geographic contexts. This last period also showed evidence of the field broadening its scope to include a variety of interdisciplinary approaches, such as social network analysis and age-related perspectives. Overall, each succeeding period reflects a more complex and nuanced discussion, evidencing the field's maturation and the evolving challenges presented by the digital divide.

2.4.2.3. Bibliographic coupling

The Bibliographic Coupling Network for 2000-2007, depicted in Figure 16, reveals a moderately connected intellectual landscape with a density of 0.507 and a cluster coefficient of 0.771, as shown in Table A.9. This suggests that while there is some interconnection between works, it is not as tight as one might find in more mature fields. The modularity measure of 0.483 indicates that the network contains discernible thematic clusters, although relatively interconnected. As illustrated in Table A.10, Vehovar et al. (2006) and Selwyn (2004) emerge as the most influential individual nodes within Cluster 1, owing to their highest DegC.

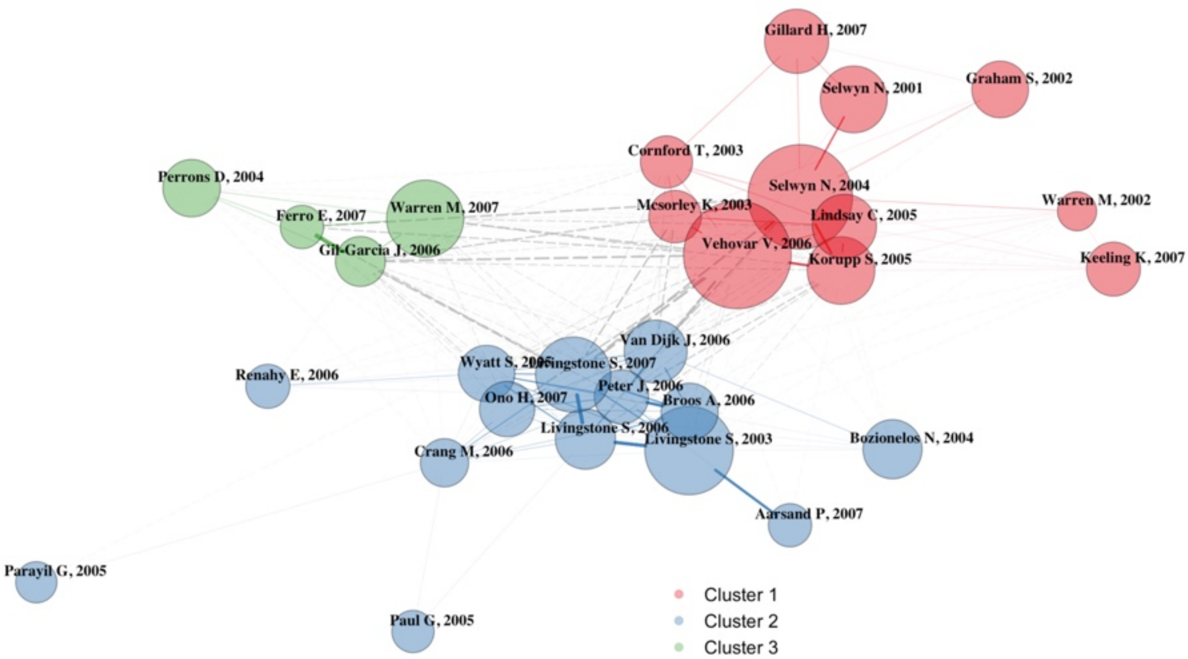

Figure 16: Bibliographic Coupling Network 2000-2007.

Source: Author's elaboration.

Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

These publications thus serve as pivotal focal points in the intellectual discourse of this period. On the other hand, Cluster 2 is notably characterised by the influential works of Livingstone from 2003 and 2007, as well as Livingstone and Helsper (2007). These publications have high DegC values and boast significant PRC scores, accentuating their broad impact within the network. Conversely, Cluster 3, comprised of only four nodes and distanced from the other two clusters, represents a specialised or emerging area within the scholarly landscape. The lack of high PRC scores for this cluster suggests that these nodes, although present in the network, have yet to gain substantial influence in shaping the academic discussion for this particular period.

Figure 17 illustrates the word cloud derived from the first Bibliographic Coupling Network, spanning the years 2000-2007. Several thematic contours shape the research front, offering deep insights into the digital divide discourse of that period. Cluster 1 accentuates the intertwining of ICT with its societal implications, emphasising individual interactions with technology and how these underscore the policy and educational dimensions. The dual notions of digital 'inclusion' and 'exclusion' are notably represented, hinting at the multifaceted challenges and opportunities that the digital landscape presents.

Figure 17:Thematic Word Clouds for Bibliographic Coupling Clusters for 2000-2007.

Source: Author's elaboration.

Meanwhile, Cluster 2 offers a generational perspective, capturing concerns that range from different age groups. In this context, the term 'health' could serve as a proxy for discussions around equitable access to digital health resources and the potential for ICT to either mitigate or exacerbate existing healthcare disparities. Cluster 3, although smaller and somewhat distant from the other clusters, focuses on contrasting rural and disadvantaged urban environments, hinting at the geographically nuanced barriers and opportunities in digital access. Notably, the prevalence of the term 'access' across all clusters reveals that the network predominantly concentrates on the first level of the digital divide, specifically addressing issues related to the availability and use of ICT. These clusters provide a broad snapshot of early 21st-century debates on the digital divide.

The Bibliographic Coupling Network for 2008-2015, as depicted in Figure 18 and further quantified in Table A.11, exhibits a high density of 0.975 and a cluster coefficient of 0.978. These metrics indicate an integrated academic discussion within the publications. However, the modularity score of 0.540 suggests some thematic separation between the clusters, echoing the nuanced topics that dominate each grouping.

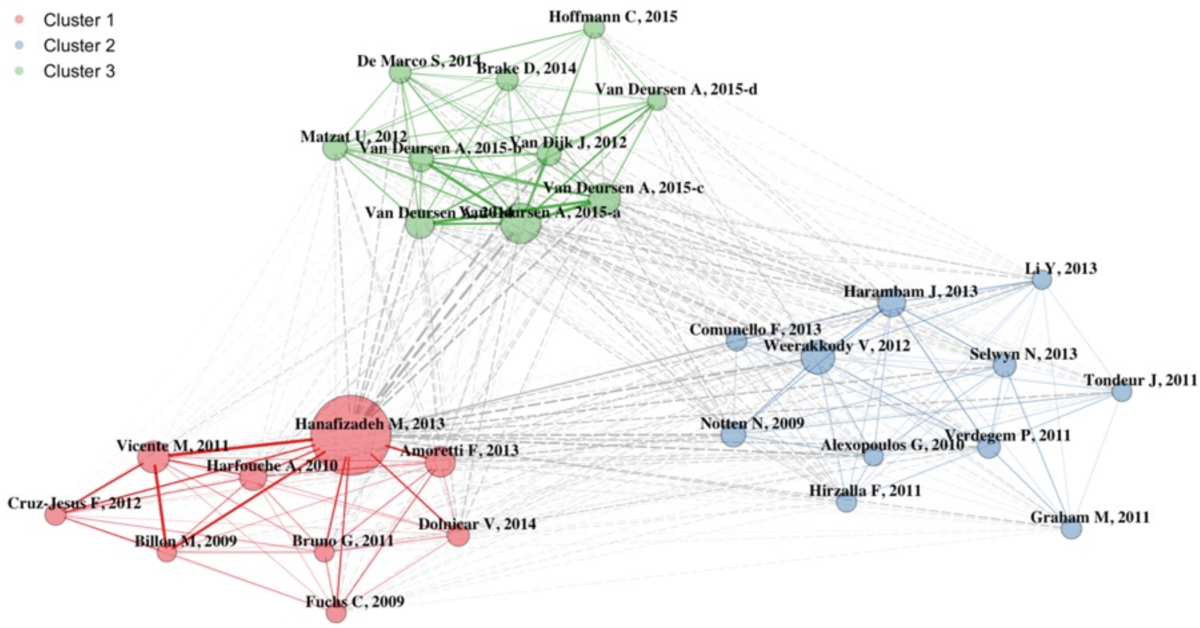

Figure 18: Bibliographic Coupling Network 2008-2015.
Source: Author's elaboration.
Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

On the node-specific metrics outlined in Table A.10, the network features a few dominant publications leading both DegC and PRC within their respective clusters. Specifically, Hanafizadeh et al. (2013) emerged as a central pillar in Cluster 1. This work acts as the linchpin around which the cluster's thematic discussions orbit during this period. In contrast, Cluster 2 is distinctive for its absence of a dominant publication in either metric, signifying a more diverse intellectual landscape. Cluster 3, however, is anchored by the work of van Deursen and van Dijk (2015)-a , which leads to DegC and PRC. Another work, Van Deursen et al. (2015)-c, complements this by registering a notable PRC score.

The thematic contours revealed by the word clouds in Figure 19 during the second Bibliographic Coupling Network for 2008-2015 illuminate an evolving focus within the academic discussion on the digital divide. Cluster 1 emphasises geographical and metric concerns, highlighting the role of regional e-readiness among individuals and indices as tools for measuring the digital divide at the country level. These topics underscore a desire for more sophisticated analytical tools to understand disparities in access.

Figure 19: Thematic Word Clouds for Bibliographic Coupling Clusters for 2008-2015.

Source: Author's elaboration.

Cluster 2 captures a more sociocultural dimension, incorporating elements such as student interactions, family dynamics, and the role of social structures in determining access and utilisation of digital resources. The topics in cluster 2 suggest that the debate has broadened to include various social factors that affect digital engagement. Notably, Cluster 3 focuses on the second-level digital divide, reflecting a growing scholarly interest in skills and usage. This marks a noticeable shift from access issues to those concerning the quality and nature of digital engagement, emphasising the importance of skilful usage and creative output. The mention of 'Dutch' might hint at more localised studies or the role of Dutch scholars in shaping this part of the discourse. These clusters reveal a nuanced and multi-layered research focus that has moved beyond mere access issues, indicating an increasingly complex academic landscape.

In the most recent period from 2016 to 2022, the Bibliographic Coupling Network, represented in Figure 20, exhibits a highly cohesive scholarly landscape with a density and cluster coefficient both at 1, as detailed in Table A.13. This suggests an intellectual environment where research topics are closely related and highly interconnected. The modularity measure 0.501 reveals a balanced yet distinct clustering of thematic relations.

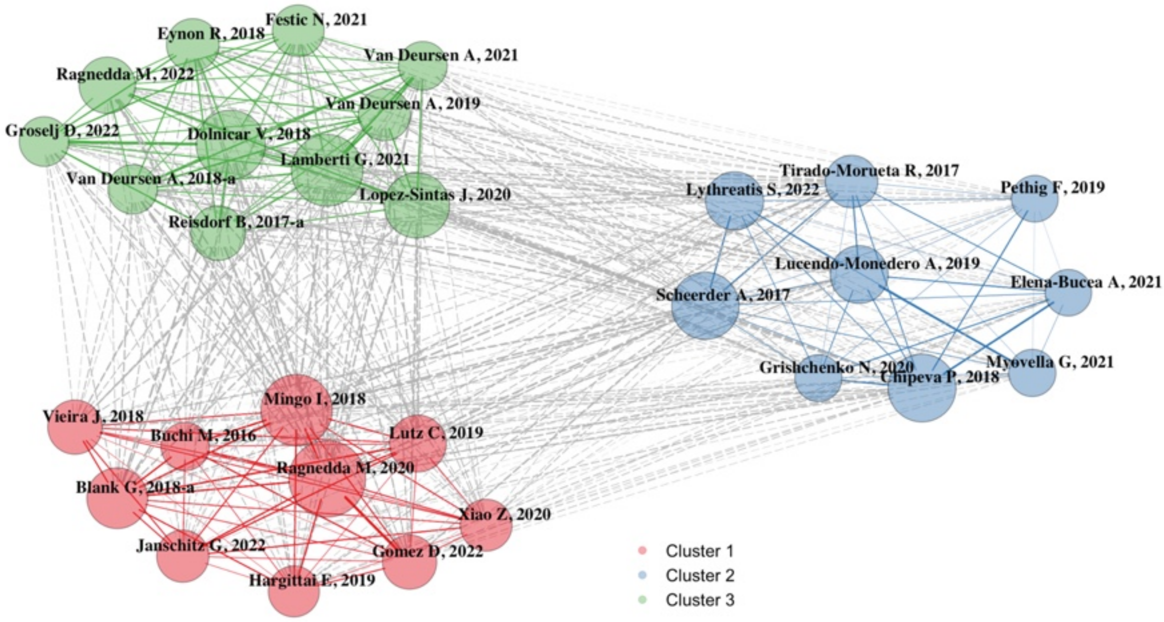

Figure 20: Bibliographic Coupling Network 2016-2022.

Source: Author's elaboration.

Note: Each node represents a publication, identified by the first author and year of publication. Some publications have multiple authors not indicated in the diagram.

Examining the node metrics in Table A.14, it is noteworthy that the highest DegC and PRC frequently coincide, implying that the most central works are also the most influential within their respective clusters. In Cluster 1, Ragnedda et al. (2020) and Mingo and Bracciale (2018) stand out regarding DegC and PRC. In Cluster 2, while Chipeva et al. (2018) and Scheerder et al. (2017) have the highest DegC and thus serve as critical nodes within this cluster, the absence of high PRC scores suggests their influence is less widely dispersed across the network. This could indicate that, despite their centrality within Cluster 2, these publications may not dominate the broader scholarly discussion.

In contrast, Cluster 3 shows multiple nodes with high DegC and PRC scores, such as Lamberti et al. (2021) and Dolnicar et al.(2018), indicating that these studies have received significant attention and recognition. Furthermore, the appearance of van Deursen and van Dijk (2019) with a significant PRC score suggests that these Dutch scholars have continued lasting impacts across various periods.

The word cloud, visualised in Figure 21 for the third Bibliographic Coupling Network spanning 2016-2022, is a compelling snapshot of the current state of digital divide research. Cluster 1 uniquely elevates the discourse through its emphasis on 'digital capital,' a refined concept introduced predominantly by Ragnedda et al. (2020). This introduces a refined, third-level perspective to the digital divide that goes beyond mere access and skills to include individuals' intangible assets in the digital world. Focusing on detailed survey models and variable selection in this cluster adds a layer of methodological rigour, further crystallising its significance.

Figure 21: Thematic Word Clouds for Bibliographic Coupling Clusters for 2016-2022.

Source: Author's elaboration.

Cluster 2 broadens the scope to regional and national scales, highlighting mainly European contexts and pointing to policy and infrastructural needs. Cluster 3 introduces a multifaceted discourse by incorporating terms like 'IoT' or Internet of Things and 'inclusion,' showcasing how the field has evolved to consider new technologies and their broader societal implications. Across these thematic groupings, the persistent mention of 'skills' and 'use' affirms the enduring relevance of second-level digital divide issues. Collectively, these clusters highlight the thematic richness and encapsulate the most pressing focal points in current digital divide research.

The progression of the bibliographic coupling from 2000 to 2022 showcases the evolving research landscape of the digital divide. The early phase (2000-2007) was characterised by foundational concepts such as access, laying the groundwork for the field. The thematic structure shifted in 2008-2015, introducing diverse aspects like regional variations, e-readiness, and cultural nuances, reflecting the field's maturation and decentralisation shown in the clusters. The most recent period, 2016-2022, further evolved, spotlighting complex themes like 'digital capital' and integrating emerging topics like IoT. Across these periods, the digital divide research has transitioned from basic to intricate, mirroring the escalating complexities of the digital landscape.

2.5. Conclusions

The evolution of leading trends, focus shifts, and key themes in European research on the digital divide can be traced through a systematic examination of the literature and network analysis over time. The co-citation networks offer a diachronic perspective on the evolving knowledge base of the digital divide, reflecting a maturation in thematic depth and complexity over time. In the field's formative stage, seminal contributions from scholars like Norris (2001) and van Dijk (2003, 2006) laid the foundation, primarily addressing the first-level digital divide related to access and availability of ICT. These early works shaped the initial discourse and catalysed a shift towards a more expansive academic inquiry. Subsequent contributions, notably from van Dijk (2005), Hargittai (2002), van Dijk and van Deursen (2014), and van Deursen and Helsper (2014), have become cornerstones of European research, extending the debate to encompass second and third-level digital divides. These later studies introduced nuanced considerations like digital skills and the diverse outcomes arising from different types of ICT use. Overall, the progression in the co-citation networks encapsulates the field's evolution from an initial, somewhat monolithic concern with access to a multi-faceted and nuanced exploration of digital inequality.

The bibliographic coupling networks provide a chronological evolution of the research front on the digital divide, highlighting increasing thematic sophistication over successive periods. During the formative years of 2000-2007, the research front focused on fundamental aspects such as the methodological challenges of studying the digital divide, as elucidated by Vehovar et al. (2006), and the political implications explored by Selwyn (2004). These foundational works established an academic framework that initially delved into policy and educational considerations. Between 2008 and 2015, the emphasis noticeably shifted. Hanafizadeh et al. (2013) provided a comprehensive literature review on the digital divide and e-readiness, while other clusters drew attention to geographical considerations and the role of indices in measuring disparities at the national level. This phase showed a growing need for advanced analytical tools to understand the digital divide. The discourse underwent further refinement in the transition to the most recent period of 2016-2022. Ragnedda et al. (2020) emerged as influential for introducing the 'digital capital' concept and establishing an index to measure it. Additionally, works like Lamberti et al. (2021), which tested van Dijk's resources and appropriation theory in the European Union, and van Deursen et al. (2021), which examined inequalities in IoT access, skills, and usage, signalled a broader thematic scope. In summary, the bibliographic coupling networks depict the field's progression from an initial focus on foundational issues to an increasingly nuanced and multi-faceted exploration shaping the current state of research on digital inequalities.

The intellectual interactions and thematic connections within European digital divide research have substantially aided in pinpointing key subtopics and literature groupings. Initial analysis of the co-citation and bibliographic coupling networks unveiled shifts in the literature's focus, with clusters demonstrating an increasingly interconnected nature, especially in recent periods. These clusters represent a broad intellectual interaction among varied research themes shown in the word clouds.

A broad perspective on the emergence of intellectual interactions, as depicted in Figure 9, highlights three country clusters that are actively collaborating in research. Certain countries, like the United Kingdom, USA, the Netherlands, Spain, Germany and Italy, stand out for their influential role in shaping digital divide discussions. Their strong representation across clusters signifies their substantial intellectual contributions to central themes in the field.

The University of Twente and the London School of Economics have emerged as leading institutions in the academic sphere. The prevalence of their publications across clusters underlines their pivotal role in advancing toward a robust digital divide research agenda, particularly in examining its second and third-level aspects. Notably, high-impact journals such as 'New Media & Society' and 'The Information Society' have consistently been channels for sharing these influential works, emphasising their vital role in circulating innovative digital divide research. Thus, these complex networks of intellectual exchanges and thematic connections uncover the interplay between various actors and institutions in the European digital divide research landscape.

Within the broader landscape of European research on the digital divide, the firm-level dimension still needs to be explored, even across diverse academic disciplines like economics, business, and management. Of the 1,609 documents in the initial sample, a mere 30 articles directly address the subject, pointing to a significant gap in the literature. This paucity of scholarly focus is particularly striking given the crucial impact digital inequities can have on firms in an increasingly digitised global economy. Moreover, the limited number of publications on the firm-level digital divide has implications for its visibility in scholarly networks and word clouds presented in the results, making its appearance less likely and further emphasising the need for targeted research in this area.

One explanation for this gap may lie in the migration of relevant debates into neighbouring streams such as digital transformation and ICT adoption. These literatures address disparities in access, skills, and usage within firms but does not necessarily frame them as a digital divide. As a result, the discussion appears fragmented across academic communities, with the risk that the firm-level perspective is diluted rather than developed as a coherent line of inquiry. This dynamic interplay of ideas illustrates the permeability of conceptual boundaries, but also underscores the need for a more systematic and explicit research agenda on the firm-level digital divide.

Such a scenario reflects a dynamic interplay of ideas across distinct research areas. However, it also underscores the urgent need for a more robust and exhaustive examination of the firm-level digital divide as a critical phenomenon. By filling this literature gap, scholars can make significant advancements in deepening our understanding of the structural, cultural and institutional dimensions of digital disparities, thereby shaping the creation of more equitable digital policies and practices at the organisational level.

In light of the current findings, several promising areas beckon for future exploration beyond the realm of the firm-level digital divide. For instance, given the scarcity of research on digital inequities at the organisational level, this represents a critical area warranting more profound scholarly attention. Moreover, emerging technologies such as generative AI, blockchain, and the pursuit of advancements in quantum computing present new challenges and opportunities for examining how these technologies might exacerbate or mitigate digital disparities in society and the business world. Understanding these factors could significantly shape future policy interventions and strategies. Finally, there is also merit in more granular research focused on specific populations or geographical regions. Such studies could examine the sociocultural dynamics that influence access to, usage of, and impact from digital technologies, thereby providing a more comprehensive understanding of the digital divide.

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Appendix A: Network and Clusters Metrics

Country Collaboration Network		
Properties	**Sample Network**	**Simplified Network**
Is connected	**TRUE**	**TRUE**
Density	0,795	0,337
Modularity	0,495	0,495
Clustering Coefficient	0,581	0,581

Table A.1. Country collaboration network properties. Source: Author's elaboration.

Vertex	Cluster	PRC	DegC
United Kingdom	1	0,101	1,000
Netherlands	1	0,036	0,277
Usa	1	0,078	0,363
Belgium	1	0,027	0,119
Canada	1	0,036	0,103
Ireland	1	0,021	0,079
China	1	0,024	0,069
Australia	1	0,032	0,070
South Africa	1	0,024	0,064
Chile	1	0,015	0,034
New Zealand	1	0,013	0,035
Philippines	1	0,014	0,021
Spain	2	0,054	0,691
Germany	2	0,042	0,340
Portugal	2	0,037	0,129
Sweden	2	0,016	0,141
Austria	2	0,037	0,124
Switzerland	2	0,015	0,119
Slovenia	2	0,014	0,059

Vertex	Cluster	PRC	DegC
Mexico	2	0,018	0,046
Hungary	2	0,005	0,022
Ecuador	2	0,013	0,026
Israel	2	0,011	0,027
Italy	3	0,046	0,341
Russia	3	0,011	0,170
Finland	3	0,031	0,150
Norway	3	0,036	0,172
France	3	0,015	0,124
Greece	3	0,011	0,091
Ukraine	3	0,007	0,042
Poland	3	0,025	0,082
Romania	3	0,015	0,059
Denmark	3	0,021	0,068
Estonia	3	0,014	0,048
India	3	0,026	0,057
Brazil	3	0,023	0,052
Japan	3	0,017	0,033
Turkey	3	0,011	0,021

Croatia	2	0,007	0,034

*Table A.2. Node level metrics for country collaboration network. **PRC**: PageRank Centrality. **DegC**: Degree of Centrality. Source: Author's Elaboration.*

Co-citation Network 2000-2007		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	1,154	0,634
Modularity	0,457	0,457
Clustering Coefficient	0,766	0,766

Table A.3. Co-citation network properties for 2000-2007. Source: Author's elaboration.

Vertex	Article	Cluster	PRC	DegC
Norris P 2001	Norris, P. (2001) - Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide	1	0,040	1,000
Castells M 2001-a	Castells, M. (2001) - The Internet Galaxy: Reflections on the Internet, Business, and Society	1	0,027	0,395
Van Dijk J 2003	Van Dijk, J. A. G. M., & Hacker, K. (2003) - The Digital Divide as a Complex and Dynamic Phenomenon	1	0,024	0,387
Servon L 2002-a	Servon, L. J. (2002) - Four Myths About the Digital Divide	1	0,023	0,288
Hargittai E 2002	Hargittai, E. (2002) - Second-Level Digital Divide: Differences in People's Online Skills	2	0,046	0,582
Bonfadelli H 2002	Bonfadelli, H. (2002) - The Internet and Knowledge Gaps: A Theoretical and Empirical Investigation	2	0,058	0,468
Dimaggio P 2001-a	DiMaggio, P., & Hargittai, E. (2001) - From the 'digital divide' to 'digital inequality': Studying Internet use as penetration increases	2	0,048	0,424
Castells M 1996	Castells, M. (1996) - The Rise of the Network Society	2	0,038	0,361
Dimaggio P 2001-b	DiMaggio, P., Hargittai, E., Neuman, W. R., & Robinson, J. P. (2001) - Social Implications of the Internet	2	0,040	0,304
Castells M 1998	Castells, M. (1998) - End of Millennium	2	0,031	0,225
Castells M 2000-a	Castells, M. (2000) - Toward a Sociology of the Network Society	2	0,012	0,288
Haddon L 2000	Haddon, L. (2000) - Social Exclusion and Information and Communication Technologies: Lessons from Studies of Single Parents and the Young Elderly	2	0,034	0,288
Van Dijk J 1999	Van Dijk, J. A. G. M. (1999) - The Network Society	2	0,037	0,295

Attewell P 2001	Attewell, P. (2001) - Comment: The First and Second Digital Divides	2	0,028	0,243
Katz J 2002-a	Katz, J. E., & Rice, R. E. (2002) - Social Consequences of Internet Use: Access, Involvement, and Interaction	2	0,043	0,308
Malecki E 2003	Malecki, E. J. (2003) - Digital Development in Rural Areas: Potentials and Pitfalls	2	0,025	0,301
Mansell R 1998	Mansell, R., & Wehn, U. (1998) - Knowledge Societies: Information Technology for Sustainable Development	2	0,015	0,230
Murdock G 2002-a	Murdock, G. (2002) - Digital Possibilities, Market Realities: The Contradictions of Communications Convergence	2	0,030	0,227
Balnaves M 1997	Balnaves, M., & Caputi, P. (1997) - Technological Wealth and the Evaluation of Information Poverty	2	0,024	0,235
Jung J 2001	Loges, W. E., & Jung, J. Y. (2001) - Exploring the Digital Divide: Internet Connectedness and Age	2	0,039	0,252
Servon L 2001	Servon, L. J., & Nelson, M. (2001) - Community Technology Centers: Narrowing the Digital Divide in Low-Income, Urban Communities	2	0,038	0,231
Compaine B 2001	Compaine, B. M. (2001) - The Digital Divide: Facing a Crisis or Creating a Myth?	3	0,053	0,747
Rogers E 1995	Rogers, E. M. (1995) - Diffusion of Innovations, 5th Edition	3	0,042	0,740
Selwyn N 2004-a	Selwyn, N. (2004) - Reconsidering Political and Popular Understandings of the Digital Divide	3	0,034	0,308
Warschauer M 2003-a	Warschauer, M. (2003) - Technology and Social Inclusion: Rethinking the Digital Divide	3	0,036	0,343
Facer K 2001-a	Facer, K., Sutherland, R., Furlong, R., & Furlong, J. (2001) - What's the Point of Using Computers?: The Development of Young People's Computer Expertise in the Home	3	0,039	0,326
Bourdieu P 1984	Bourdieu, P. (1984) - Distinction: A Social Critique of the Judgement of Taste	3	0,029	0,229
Attewell P 1999	Attewell, P., & Battle, J. (1999) - Home Computers and School Performance	3	0,024	0,325
Chen W 2003	Chen, W., & Wellman, B. (2003) - Charting and Bridging Digital Divides	3	0,032	0,244
Miller D 2000	Miller, D. (2000) - The Fame of Trinis: Websites as Traps	3	0,012	0,237

*Table A.4. Node level metrics for co-citation network 2000-2007. **PRC**: PageRank Centrality. **DegC**: Degree of Centrality. Source: Author's Elaboration.*

Co-citation Network 2008-2015		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	5,074	0,982

Modularity	0,478	0,478
Clustering Coefficient	0,984	0,984

Table A.5. Co-citation network properties for 2008-2015. Source: Author's elaboration.

Vertex	Article	Cluster	PRC	DegC
Norris P 2001	Norris, P. (2001) - Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide	1	0,059	1,000
Van Dijk J 2003	Van Dijk, J. A. G. M., & Hacker, K. (2003) - The Digital Divide as a Complex and Dynamic Phenomenon	1	0,041	0,570
Selwyn N 2004-a	Selwyn, N. (2004) - Reconsidering Political and Popular Understandings of the Digital Divide	1	0,043	0,606
Warschauer M 2003-a	Warschauer, M. (2003) - Technology and Social Inclusion: Rethinking the Digital Divide	1	0,029	0,268
Warschauer M 2003-b	Warschauer, M. (2003) - Demystifying the Digital Divide	1	0,031	0,350
Compaine B 2001-a	Compaine, B. M. (2001) - The Digital Divide: Facing a Crisis or Creating a Myth?	1	0,028	0,306
Barzilai-Nahon K 2006	Barzilai-Nahon, K. (2006) - Gaps and Bits: Conceptualizing Measurements for Digital Divides	1	0,023	0,321
Gunkel D 2003	Gunkel, D. (2003) - Second Thoughts: Toward a Critique of the Digital Divide	1	0,024	0,231
Katz J 2002-a	Katz, J. E., Rice, R. E. (2002) - Social Consequences of Internet Use: Access, Involvement, and Interaction	1	0,028	0,251
Van Dijk J 2005-a	Van Dijk, J. A. G. M. (2005) - The Deepening Divide: Inequality in the Information Society	2	0,061	0,644
Van Dijk J 2006-a	Van Dijk, J. A. G. M. (2006) - Digital Divide Research, Achievements and Shortcomings	2	0,051	0,575
Hargittai E 2002	Hargittai, E. (2002) - Second-Level Digital Divide: Differences in People's Online Skills	2	0,047	0,444
Dimaggio P 2004	DiMaggio, P., Hargittai, E., Neuman, W. R., Robinson, J. P. (2004) - Digital Inequality: From Unequal Access to Differentiated Use	2	0,048	0,523
Hargittai E 2008-a	Hargittai, E., Hinnant, A. (2008) - Digital Inequality: Differences in Young Adults' Use of the Internet	2	0,045	0,414
Livingstone S 2007-a	Livingstone, S., & Helsper, E. (2007) - Gradations in digital inclusion: children, young people and the digital divide	2	0,043	0,434
Davis F 1989-a	Davis, F. D. (1989) - Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology	2	0,019	0,264
Mossberger K 2003	Mossberger, K., Tolbert, C. J., & Stansbury, M. (2003) - Virtual Inequality: Beyond the Digital Divide	2	0,039	0,376
Bonfadelli H 2002	Bonfadelli, H. (2002) - The Internet and Knowledge Gaps: A Theoretical and Empirical Investigation	2	0,035	0,291

Dimaggio P 2001-a	DiMaggio, P., & Hargittai, E. (2001) - From the 'digital divide' to 'digital inequality': Studying Internet use as penetration increases	2	0,026	0,285
Hargittai E 2010-a	Hargittai, E. (2010) - Digital Na(t)ives? Variation in Internet Skills and Uses Among Members of the "Net Generation"	2	0,027	0,216
Selwyn N 2006-a	Selwyn, N. (2006) - Digital Division or Digital Decision? A Study of Non-Users and Low Users of Computers	2	0,025	0,212
Chinn M 2007	Chinn, M. D., & Fairlie, R. W. (2007) - The Determinants of the Global Digital Divide: A Cross-Country Analysis of Computer and Internet Penetration	3	0,031	0,274
Kiiski S 2002	Kiiski, S., & Pohjola, M. (2002) - Cross-Country Diffusion of the Internet	3	0,034	0,291
Hargittai E 1999	Hargittai, E. (1999) - The Digital Divide and What To Do About It	3	0,030	0,256
Corrocher N 2002	Corrocher, N., & Ordanini, A. (2002) - Measuring the Digital Divide: A Framework for the Analysis of Cross-Country Differences	3	0,025	0,232
Chen W 2004	Chen, W., & Wellman, B. (2004) - The Global Digital Divide Within and Between Countries	3	0,020	0,202
Demoussis M 2006	Demoussis, M., & Giannakopoulos, N. (2006) - Facets of the Digital Divide in Europe: Determination and Extent of Internet Use	3	0,021	0,205
Ono H 2007	Ono, H., Zavodny, M. (2007) - Immigrants, English Ability and the Digital Divide	3	0,024	0,202
Beilock R 2003	Beilock, R., Dimitrova, D. (2003) - An Exploratory Model of Inter-Country Internet Diffusion	3	0,024	0,207
Hoffman D 1998-a	Hoffman, D. L., & Novak, T. P. (1998) - Bridging the Digital Divide: The Impact of Race on Computer Access and Internet Use	3	0,015	0,203

*Table A.6. Node level metrics for co-citation network 2008-2015. **PRC**: PageRank Centrality. **DegC**: Degree of Centrality. Source: Author's Elaboration.*

Co-citation Network 2016-2022		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	11,497	0,986
Modularity	0,458	0,458
Clustering Coefficient	0,986	0,986

Figure A.7. Co-citation network properties for 2016-2022. Source: Author's elaboration.

Vertex	Article	Cluster	PRC	DegC
Van Deursen A 2015-a	Van Deursen, A. J. A. M., Helsper, E. J. (2015) - The Third-Level Digital Divide: Who Benefits Most from Being Online?	1	0,061	0,985

Van Dijk J 2014	Van Dijk, J. A. G. M., Van Deursen, A. J. A. M. (2014) - Digital Skills: Unlocking the Information Society	1	0,061	1,000
Van Dijk J 2005-a	Van Dijk, J. A. G. M. (2005) - The Deepening Divide: Inequality in the Information Society	1	0,055	0,916
Hargittai E 2002	Hargittai, E. (2002) - Second Level Digital Divide: Differences in People's Online Skills	1	0,049	0,652
Scheerder A 2017	Scheerder, A., Van Deursen, A.J.A.M., Van Dijk, J.A.G.M. (2017) - Determinants of Internet skills, uses and outcomes. A systematic review of the second- and third-level digital divide	1	0,040	0,578
Helsper E 2012-a	Helsper, E. (2012) - A Corresponding Fields Model for the Links Between Social and Digital Exclusion	1	0,037	0,380
Blank G 2014-a	Blank, G. (2014) - The Digital Divide Among Twitter Users and Its Implications for Social Research	1	0,038	0,405
Van Deursen A 2019	Van Deursen, A.J.A.M., Van Dijk, J.A.G.M. (2018) - The first-level digital divide shifts from inequalities in physical access to inequalities in material access	1	0,027	0,317
Van Deursen A 2017-a	Van Deursen, A.J.A.M., Van Laar, E., Van Dijk, J.A.G.M., De Haan, J. (2017) - The relation between 21st-century skills and digital skills: A systematic literature review	1	0,028	0,287
Wei K 2011	Wei, K.K., Teo, H.H., Chan, H.C., Tan, B.C.Y. (2011) - Conceptualizing and Testing a Social Cognitive Model of the Digital Divide	1	0,024	0,300
Norris P 2001	Norris, P. (2001) - Digital Divide: Civic Engagement, Information Poverty, and the Internet Worldwide	2	0,028	0,659
Van Dijk J 2006-a	Van Dijk, J. A. G. M. (2006) - Digital Divide Research, Achievements and Shortcomings	2	0,030	0,624
Van Dijk J 2003	Van Dijk, J. A. G. M., & Hacker, K. (2003) - The Digital Divide as a Complex and Dynamic Phenomenon	2	0,022	0,440
Dimaggio P 2001-a	DiMaggio, P., Hargittai, E. (2001) - From the ‘Digital Divide’ to ‘Digital Inequality’: Studying Internet Use as Penetration Increases	2	0,019	0,338
Friemel T 2016	Friemel, T. (2016) - The Digital Divide Has Grown Old: Determinants of a Digital Divide Among Seniors	2	0,018	0,363
Davis F 1989	Davis, F. D. (1989) - Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology	2	0,020	0,349
Venkatesh V 2003-a	Venkatesh, V., Sykes, T.A. (2013) - Digital Divide Initiative Success in Developing Countries: A Longitudinal Field Study in a Village in India	2	0,019	0,364
Vicente M 2011-a	Vicente, M., López, A. J. (2011) - Assessing the Regional Digital Divide Across the European Union 27	2	0,015	0,297
Hargittai E 2008-a	Hargittai, E., Hinnant, A. (2008) - Digital Inequality: Differences in Young Adults' Use of the Internet	3	0,054	0,677
Van Deursen A 2011	Van Deursen, A.J.A.M., Van Dijk, J.A.G.M. (2011) - Internet Skills and the Digital Divide Is this acceptable?	3	0,039	0,530

Zillien N 2009-a	Zillien, N., Hargittai, E. (2009) - Digital Distinction: Status-Specific Types of Internet Usage	3	0,050	0,567
Selwyn N 2004	Selwyn, N. (2004) - Reconsidering Political and Popular Understandings of the Digital Divide	3	0,039	0,516
Dimaggio P 2004	DiMaggio, P., Hargittai, E., Neuman, W. R., Robinson, J. P. (2004) - Digital Inequality: From Unequal Access to Differentiated Use	3	0,046	0,568
Hargittai E 2010-a	Hargittai, E. (2010) - Digital Na(t)ives? Variation in Internet Skills and Uses Among Members of the "Net Generation"	3	0,035	0,409
Prensky M 2001-a	Prensky, M. (2001) - Digital Natives, Digital Immigrants	3	0,017	0,307
Livingstone S 2007-a	Livingstone, S. (2007) - Gradations in Digital Inclusion: Children, Young People and the Digital Divide	3	0,031	0,294
Bonfadelli H 2002	Bonfadelli, H. (2002) - The Internet and Knowledge Gaps: A Theoretical and Empirical Investigation	3	0,028	0,293
Robinson L 2015-a	Robinson, L., Cotten, S.R., Ono, H., Quan-Haase, A., Mesch, G., Chen, W., Schulz, J., Hale, T.M., Stern, M.J. (2015) - Digital inequalities and why they matter	3	0,022	0,292
Robinson L 2009	Robinson, L. (2009) - A Taste For The Necessary: A Bourdieuian Approach to Digital Inequality	3	0,026	0,278
Haight M 2014	Haight, M., Quan-Haase, A., Corbett, B. A. (2014) - Revisiting the Digital Divide in Canada: The Impact of Demographic Factors on Access to the Internet, Level of Online Activity, and Social Networking Site Usage	3	0,025	0,284

Table A.8. Node level metrics for co-citation network 2016-2022. ***PRC****: PageRank Centrality.* ***DegC****: Degree of Centrality. Source: Author's Elaboration.*

Bibliographic Coupling Network 2000-2007		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	1,172	0,507
Modularity	0,483	0,483
Clustering Coefficient	0,771	0,771

Figure A.9. Co-citation network properties for 2000-2007. Source: Author's elaboration.

Vertex	Article	Cluster	PRC	DegC
Selwyn N, 2001	Selwyn N; Gorard S; Williams S (2001) - Digital Divide Or Digital Opportunity? The Role Of Technology In Overcoming Social Exclusion In Us Education	1	0,019	0,621
Graham S, 2002	Graham S (2002) - Bridging Urban Digital Divides? Urban Polarisation And Information And Communications Technologies (Icts)	1	0,013	0,526
Warren M, 2002	Warren M (2002) - Digital Divides And The Adoption Of Information And Communication Technologies In The Uk Farm Sector	1	0,016	0,363
Cornford T, 2003	Cornford T; Klecun-Dabrowska E (2003) - Social Exclusion And Information Systems In Community Healthcare	1	0,025	0,484
Mcsorley K, 2003	Mcsorley K (2003) - The Secular Salvation Story Of The Digital Divide	1	0,034	0,487
Selwyn N, 2004	Selwyn N (2004) - Reconsidering Political And Popular Understandings Of The Digital Divide	1	0,083	0,971
Korupp S, 2005	Korupp S; Szydlik M (2005) - Causes And Trends Of The Digital Divide	1	0,044	0,627
Lindsay C, 2005	Lindsay C (2005) - Employability, Services For Unemployed Job Seekers And The Digital Divide	1	0,046	0,595
Vehovar V, 2006	Vehovar V; Sicherl P; Husing T; Dolnicar V (2006) - Methodological Challenges Of Digital Divide Measurements	1	0,057	1,000
Keeling K, 2007	Keeling K; Macaulay L; Mcgoldrick P (2007) - Ditv And E-Commerce Among Disadvantaged Community Groups	1	0,014	0,500
Gillard H, 2007	Gillard H; Mitev N; Scott S (2007) - Ict Inclusion And Gender: Tensions In Narratives Of Network Engineer Training	1	0,019	0,595
Livingstone S, 2003	Livingstone S (2003) - Children's Use Of The Internet: Reflections On The Emerging Research Agenda	2	0,055	0,820
Bozionelos N, 2004	Bozionelos N (2004) - Socio-Economic Background And Computer Use: The Role Of Computer Anxiety And Computer Experience In Their Relationship	2	0,014	0,549
Wyatt S, 2005	Wyatt S; Henwood F; Hart A; Smith J (2005) - The Digital Divide, Health Information And Everyday Life	2	0,044	0,523
Parayil G, 2005	Parayil G (2005) - The Digital Divide And Increasing Returns: Contradictions Of Informational Capitalism	2	0,007	0,382
Paul G, 2005	Paul G; Stegbauer C (2005) - Is The Digital Divide Between Young And Elderly People Increasing?	2	0,008	0,392
Crang M, 2006	Crang M; Crosbie T; Graham S (2006) - Variable Geometries Of Connection: Urban Digital Divides And The Uses Of Information Technology	2	0,035	0,448
Livingstone S, 2006	Livingstone S (2006) - Drawing Conclusions From New Media Research: Reflections And Puzzles Regarding Children's Experience Of The Internet	2	0,063	0,559
Van Dijk J, 2006	Van Dijk J (2006) - Digital Divide Research, Achievements And Shortcomings	2	0,041	0,585
Peter J, 2006	Peter J; Valkenburg P (2006) - Adolescents' Internet Use: Testing The "Disappearing Digital Divide" Versus The "Emerging Digital Differentiation" Approach	2	0,061	0,503
Broos A, 2006	Broos A; Roe K (2006) - The Digital Divide In The Playstation Generation: Self-Efficacy, Locus Of Control And Ict Adoption Among Adolescents	2	0,050	0,529

Renahy E, 2006	Renahy E; Chauvin P (2006) - Internet Uses For Health Information Seeking A Literature Review	2	0,013	0,408
Ono H, 2007	Ono H; Zavodny M (2007) - Digital Inequality: A Five Country Comparison Using Microdata	2	0,034	0,513
Livingstone S, 2007	Livingstone S; Helsper E (2007) - Gradations In Digital Inclusion: Children, Young People And The Digital Divide	2	0,068	0,699
Aarsand P, 2007	Aarsand P (2007) - Computer And Video Games In Family Life: The Digital Divide As A Resource In Intergenerational Interactions	2	0,018	0,402
Perrons D, 2004	Perrons D (2004) - Understanding Social And Spatial Divisions In The New Economy: New Media Clusters And The Digital Divide	3	0,017	0,533
Gil-Garcia J, 2006	Gil-Garcia J; Helbig N; Ferro E (2006) - Is It Only About Internet Access? An Empirical Test Of A Multi-Dimensional Digital Divide	3	0,041	0,464
Warren M, 2007	Warren M (2007) - The Digital Vicious Cycle: Links Between Social Disadvantage And Digital Exclusion In Rural Areas	3	0,024	0,716
Ferro E, 2007	Ferro E; Gil-Garcia J; Helbig N (2007) - The Digital Divide Metaphor: Understanding Paths To It Literacy	3	0,038	0,402

*Table A.10. Node level metrics for co-citation network 2000-2007. **PRC**: PageRank Centrality. **DegC**: Degree of Centrality. Source: Author's Elaboration.*

Bibliographic Coupling 2008-2015		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	5,076	0,975
Modularity	0,540	0,540
Clustering Coefficient	0,978	0,978

Figure A.11. Co-citation network properties for 2008-2015. Source: Auhtor's elaboration.

Vertex	**Article**	**Cluster**	**PRC**	**DegC**
Billon M, 2009	Billon M; Marco R; Lera-Lopez F (2009) - Disparities In Ict Adoption: A Multidimensional Approach To Study The Cross-Country Digital Divide	1	0,036	0,241
Fuchs C, 2009	Fuchs C (2009) - The Role Of Income Inequality In A Multivariate Cross-National Analysis Of The Digital Divide	1	0,026	0,249
Harfouche A, 2010	Harfouche A (2010) - Sesame Street Effect: Analyzing The Antecedents Of The E-Access And The E-Skills Divides At The Macro And Micro Levels	1	0,031	0,343
Vicente M, 2011	Vicente M; Lopez A (2011) - Assessing The Regional Digital Divide Across The European Union-27	1	0,044	0,398

Bruno G, 2011	Bruno G; Esposito E; Genovese A; Gwebu K (2011) - A Critical Analysis Of Current Indexes For Digital Divide Measurement	1	0,030	0,247
Cruz-Jesus F, 2012	Cruz-Jesus F; Oliveira T; Bacao F (2012) - Digital Divide Across The European Union	1	0,030	0,265
Amoretti F, 2013	Amoretti F; Musella F (2013) - Governing Digital Divides: Power Structures And Ict Strategies In A Global Perspective	1	0,031	0,378
Hanafizadeh M, 2013	Hanafizadeh M; Hanafizadeh P; Bohlin E (2013) - Digital Divide And E-Readiness: Trends And Gaps	1	0,065	1,000
Dolnicar V, 2014	Dolnicar V; Prevodnik K; Vehovar V (2014) - Measuring The Dynamics Of Information Societies: Empowering Stakeholders Amid The Digital Divide	1	0,025	0,278
Notten N, 2009	Notten N; Peter J; Kraaykamp G; Valkenburg P (2009) - Research Note: Digital Divide Across Bordersa Cross-National Study Of Adolescents Use Of Digital Technologies	2	0,030	0,309
Alexopoulos G, 2010	Alexopoulos G; Koutsouris A; Tzouramani I (2010) - Adoption And Use Of Icts Among Rural Youth: Evidence From Greece	2	0,027	0,245
Graham M, 2011	Graham M (2011) - Time Machines And Virtual Portals: The Spatialities Of The Digital Divide	2	0,022	0,257
Tondeur J, 2011	Tondeur J; Sinnaeve I; Van Houtte M; Van Braak J (2011) - Ict As Cultural Capital: The Relationship Between Socioeconomic Status And The Computer-Use Profile Of Young People	2	0,023	0,247
Hirzalla F, 2011	Hirzalla F; Van Zoonen L; De Ridder J (2011) - Internet Use And Political Participation: Reflections On The Mobilization/Normalization Controversy	2	0,025	0,250
Verdegem P, 2011	Verdegem P (2011) - Social Media For Digital And Social Inclusion: Challenges For Information Society 2.0 Research & Policies	2	0,030	0,285
Weerakkody V, 2012	Weerakkody V; Dwivedi Y; El-Haddadeh R; Almuwil A; Ghoneim A (2012) - Conceptualizing E-Inclusion In Europe: An Explanatory Study	2	0,034	0,421
Harambam J, 2013	Harambam J; Aupers S; Houtman D (2013) - The Contentious Gap: From Digital Divide To Cultural Beliefs About Online Interactions	2	0,038	0,349
Li Y, 2013	Li Y; Ranieri M (2013) - Educational And Social Correlates Of The Digital Divide For Rural And Urban Children: A Study On Primary School Students In A Provincial City Of China	2	0,025	0,242
Comunello F, 2013	Comunello F (2013) - From The Digital Divide To Multiple Divides: Technology, Society, And New Media Skills	2	0,027	0,255
Selwyn N, 2013	Selwyn N; Facer K (2013) - Beyond Digital Divide: Toward An Agenda For Change	2	0,027	0,286
Matzat U, 2012	Matzat U; Sadowski B (2012) - Does The "Do-It-Yourself Approach" Reduce Digital Inequality? Evidence Of Self-Learning Of Digital Skills	3	0,033	0,304
Van Dijk J, 2012	Van Dijk J (2012) - The Evolution Of The Digital Divide: The Digital Divide Turns To Inequality Of Skills And Usage	3	0,036	0,300
Van Deursen A, 2014	Van Deursen A; Van Dijk J (2014) - The Digital Divide Shifts To Differences In Usage	3	0,044	0,360

Brake D, 2014	Brake D (2014) - Are We All Online Content Creators Now? Web 2.0 And Digital Divides	3	0,025	0,272
De Marco S, 2014	De Marco S; Robles J; Antino M (2014) - Digital Skills As A Conditioning Factor For Digital Political Participation	3	0,031	0,272
Van Deursen A, 2015-a	Van Deursen A; Van Dijk J (2015) - Toward A Multifaceted Model Of Internet Access For Understanding Digital Divides: An Empirical Investigation	3	0,059	0,504
Van Deursen A, 2015-b	Van Deursen A; Van Dijk J (2015) - Internet Skill Levels Increase, But Gaps Widen: A Longitudinal Cross-Sectional Analysis (2010-2013) Among The Dutch Population	3	0,040	0,306
Hoffmann C, 2015	Hoffmann C; Lutz C; Meckel M (2015) - Content Creation On The Internet: A Social Cognitive Perspective On The Participation Divide	3	0,025	0,260
Van Deursen A, 2015-c	Van Deursen A; Van Dijk J; Ten Klooster P (2015) - Increasing Inequalities In What We Do Online: A Longitudinal Cross Sectional Analysis Of Internet Activities Among The Dutch Population (2010 To 2013) Over Gender, Age, Education, And Income	3	0,050	0,398
Van Deursen A, 2015-d	Van Deursen A; Van Dijk J (2015) - New Media And The Digital Divide	3	0,032	0,242

Table A.12. Node level metrics for co-citation network 2008-2015. ***PRC****: PageRank Centrality.* ***DegC****: Degree of Centrality. Source: Author's Elaboration.*

Bibliographic Coupling 2016-2022		
Properties	**Sample Network**	**Simplified Network**
Is connected	TRUE	TRUE
Density	8,368	1
Modularity	0,501	0,501
Clustering Coefficient	1	1

Figure A.13. Co-citation network properties for 2016-2022. Source: Author's elaboration.

Vertex	Article	Cluster	PRC	DegC
Buchi M, 2016	Buchi M; Just N; Latzer M (2016) - Modeling The Second-Level Digital Divide: A Five-Country Study Of Social Differences In Internet Use	1	0,033	0,630
Vieira J, 2018	Vieira J (2018) - Media And Generations In Portugal	1	0,028	0,708
Blank G, 2018-a	Blank G; Lutz C (2018) - Benefits And Harms From Internet Use: A Differentiated Analysis Of Great Britain	1	0,038	0,792
Mingo I, 2018	Mingo I; Bracciale R (2018) - The Matthew Effect In The Italian Digital Context: The Progressive Marginalisation Of The "Poor"	1	0,040	0,930
Hargittai E, 2019	Hargittai E; Piper A; Morris M (2019) - From Internet Access To Internet Skills: Digital Inequality Among Older Adults	1	0,028	0,664

Lutz C, 2019	Lutz C (2019) - Digital Inequalities In The Age Of Artificial Intelligence And Big Data	1	0,033	0,741
Xiao Z, 2020	Xiao Z (2020) - 'You Are Too Out!': A Mixed Methods Study Of The Ways In Which Digital Divides Articulate Status And Power In China	1	0,029	0,676
Ragnedda M, 2020	Ragnedda M; Ruiu M; Addeo F (2020) - Measuring Digital Capital: An Empirical Investigation	1	0,043	1,000
Janschitz G, 2022	Janschitz G; Penker M (2022) - How Digital Are 'Digital Natives' Actually? Developing An Instrument To Measure The Degree Of Digitalisation Of University Students - The Dds-Index	1	0,031	0,680
Gomez D, 2022	Gomez D; Ragnedda M; Ruiu M (2022) - Digital Practices Across The Uk Population: The Influence Of Socio-Economic And Techno-Social Variables In The Use Of The Internet	1	0,033	0,706
Scheerder A, 2017	Scheerder A; Van Deursen A; Van Dijk J (2017) - Determinants Of Internet Skills, Uses And Outcomes. A Systematic Review Of The Second- And Third-Level Digital Divide	2	0,032	0,877
Tirado-Morueta R, 2017	Tirado-Morueta R; Mendoza-Zambrano D; Aguaded-Gomez J; Marin-Gutierrez I (2017) - Empirical Study Of A Sequence Of Access To Internet Use In Ecuador	2	0,028	0,684
Chipeva P, 2018	Chipeva P; Cruz-Jesus F; Oliveira T; Irani Z (2018) - Digital Divide At Individual Level: Evidence For Eastern And Western European Countries	2	0,034	0,885
Lucendo-Monedero A, 2019	Lucendo-Monedero A; Ruiz-Rodriguez F; Gonzalez-Relano R (2019) - Measuring The Digital Divide At Regional Level. A Spatial Analysis Of The Inequalities In Digital Development Of Households And Individuals In Europe	2	0,034	0,754
Pethig F, 2019	Pethig F; Kroenung J (2019) - Specialized Information Systems For The Digitally Disadvantaged	2	0,020	0,608
Grishchenko N, 2020	Grishchenko N (2020) - The Gap Not Only Closes: Resistance And Reverse Shifts In The Digital Divide In Russia	2	0,026	0,612
Myovella G, 2021	Myovella G; Karacuka M; Haucap J (2021) - Determinants Of Digitalization And Digital Divide In Sub-Saharan African Economies: A Spatial Durbin Analysis	2	0,025	0,616
Elena-Bucea A, 2021	Elena-Bucea A; Cruz-Jesus F; Oliveira T; Coelho P (2021) - Assessing The Role Of Age, Education, Gender And Income On The Digital Divide: Evidence For The European Union	2	0,027	0,605
Lythreatis S, 2022	Lythreatis S; Singh S; El-Kassar A (2022) - The Digital Digital Divide: A Review And Future Research Agenda	2	0,028	0,757
Reisdorf B, 2017-a	Reisdorf B; Groselj D (2017) - Internet (Non-)Use Types And Motivational Access: Implications For Digital Inequalities Research	3	0,036	0,712
Eynon R, 2018	Eynon R; Deetjen U; Malmberg L (2018) - Moving On Up In The Information Society? A Longitudinal Analysis Of The Relationship Between Internet Use And Social Class Mobility In Britain	3	0,034	0,685

Van Deursen A, 2018-a	Van Deursen A; Helsper E (2018) - Collateral Benefits Of Internet Use: Explaining The Diverse Outcomes Of Engaging With The Internet	3	0,037	0,643
Dolnicar V, 2018	Dolnicar V; Groselj D; Hrast M; Vehovar V; Petrovcic A (2018) - The Role Of Social Support Networks In Proxy Internet Use From The Intergenerational Solidarity Perspective	3	0,045	0,899
Van Deursen A, 2019	Van Deursen A; Van Dijk J (2019) - The First-Level Digital Divide Shifts From Inequalities In Physical Access To Inequalities In Material Access	3	0,039	0,680
Lopez-Sintas J, 2020	Lopez-Sintas J; Lamberti G; Sukphan J (2020) - The Social Structuring Of The Digital Gap In A Developing Country. The Impact Of Computer And Internet Access Opportunities On Internet Use In Thailand	3	0,037	0,849
Lamberti G, 2021	Lamberti G; Lopez-Sintas J; Sukphan J (2021) - The Social Process Of Internet Appropriation: Living In A Digitally Advanced Country Benefits Less Well-Educated Europeans	3	0,046	0,933
Festic N, 2021	Festic N; Buchi M; Latzer M (2021) - It's Still A Thing: Digital Inequalities And Their Evolution In The Information Society	3	0,032	0,673
Van Deursen A, 2021	Van Deursen A; Van Der Zeeuw A; De Boer P; Jansen G; Van Rompay T (2021) - Digital Inequalities In The Internet Of Things: Differences In Attitudes, Material Access, Skills, And Usage	3	0,036	0,634
Ragnedda M, 2022	Ragnedda M; Ruiu M; Addeo F (2022) - The Self-Reinforcing Effect Of Digital And Social Exclusion: The Inequality Loop	3	0,033	0,733
Groselj D, 2022	Groselj D; Reisdorf B; Dolnicar V; Patrovcic A (2022) - A Decade Of Proxy Internet Use: The Changing Role Of Socio-Demographics And Family Support In Nonusers' Indirect Internet Access To Online Services	3	0,035	0,647

Table A.14. Node level metrics for co-citation network 2016-2022. ***PRC****: PageRank Centrality.* ***DegC****: Degree of Centrality. Source: Author's Elaboration.*

Chapter 3 - Assessing Digital Integration in Firms: A Framework for Disparities in Access, Skills, and Usage

Abstract: This chapter provides a theoretical examination of the digital divide among firms through the Resources and Technology Integration Framework (RTIF). Building on Van Dijk's Resources and Appropriation Theory (RAT), the RTIF is adapted to account for firm-level contextual factors, including firm size, sectoral heterogeneities, regional differences, institutional dynamics, and the market structures of digital technologies, which are often shaped by monopolistic and oligopolistic players. Using a theory adaptation approach, the framework is refined through a literature review, historical analysis, and the re-conceptualisation of core and contextual constructs, ensuring its alignment with the complexities of digital adoption at the organisational level. The framework broadens the scope of analysis from foundational technologies such as internet connectivity to advanced digital tools, including artificial intelligence, cloud computing, and predictive analytics, reflecting the layered and iterative nature of digital technology integration. These technologies are reshaping business processes, disrupting established routines, and introducing new competitive dynamics, yet their uneven adoption further accentuates existing disparities. The chapter highlights how resource availability, institutional support, and technological disruptions shape firms' digital trajectories, particularly during stable periods and disruptive events. Additionally, it underscores the role of industrial policies and targeted interventions in mitigating digital disparities and fostering equitable technological integration. This theoretical contribution enhances our understanding of firm-level digital inequalities and provides a conceptual foundation for analysing the adoption and impact of advanced digital technologies. Furthermore, it sets the stage for empirical validation in subsequent chapters, where the RTIF will be tested using firm-level data from Italy to assess its explanatory power in real-world digital adoption dynamics.

Keywords: Digital divide, theory adaptation, firm level, access, skills, usage.

JEL Classification: O33, L86, M15, 038, D83.

3.1. Introduction

Digital technologies are pivotal in shaping contemporary business practices, empowering organisations to enhance operational efficiency, optimise processes, and explore innovative avenues for value creation (Øverby & Audestad, 2021). Advanced tools such as cloud computing, artificial intelligence, and predictive analytics are transforming how firms allocate resources, streamline workflows, and engage with their customers (Siebel, 2019). However, the uneven adoption of these technologies highlights persistent disparities, collectively referred to as the digital divide. This chapter investigates these disparities at the organisational level, examining how firm size, sector-specific demands, and regional contexts influence digital adoption. By focusing on the core constructs of access, skills, and usage, the chapter explores their role in driving or inhibiting digital transformation within firms.

The digital divide concept formally emerged in the mid-1990s when it was coined by two journalists, Webber and Harmon, in an article for the Los Angeles Times (Gunkel, 2003). The term was soon popularised by the National Telecommunications and Information Administration (NTIA) in the United States, which used census data to highlight growing inequalities between those with access to information technologies and those without (van Dijk, 2005, 2020). This initial discussion primarily focused on the importance of personal computers and the Internet as crucial technologies for social and economic participation (Norris, 2001; van Dijk & Hacker, 2003). However, even before the 1990s, when the term "digital divide" gained attention, disparities in access, skills, and usage of digital technologies were already evident, particularly at the firm level.

Breakthroughs in transistor and semiconductor technology significantly reduced the cost of computing, making personal computers accessible to households and small businesses. By the mid-1990s, internet connectivity became increasingly widespread in developed countries, shaping discussions around digital access for individuals and enterprises. This period marked the emergence of the first level digital divide, initially defined by disparities in access to personal computers and the internet (Norris, 2001; van Dijk, 2005).

As access improved, research shifted toward the second-level digital divide, which highlighted inequalities in digital skills and technology use. Studies have found that economically disadvantaged and less-educated individuals struggle to fully leverage digital tools, thereby limiting their ability to benefit from technological advancements (Hargittai, 2002; van Deursen et al., 2016). This led to the identification of a usage gap, which revealed disparities in how digital technologies were employed, whether for productive activities such as education and career development or primarily for entertainment (van Deursen & van Dijk, 2014). More recently, the third-level digital divide has extended the debate to outcomes, examining the unequal social, economic, and cultural benefits and risks derived from digital participation. This perspective has also raised concerns about privacy, surveillance, and health risks, including digital addiction (Ragnedda, 2017; van Deursen & Helsper, 2015; Zuboff, 2019).

Research on the digital divide has predominantly focused on individual-level disparities, emphasising social inclusion, economic mobility, and civic participation (Castillo-Tellez, 2023). However, firm-level digital disparities remain underexplored, despite their implications for competitiveness and technological integration. Existing theories, such as the Diffusion of Innovations (DOI) (Steiber et al., 2020) and the Technology-Organisation-Environment (TOE) framework (El-Haddadeh, 2020), explain why and how firms adopt digital technologies, yet they do not fully address how disparities emerge and persist across firms over time. These models often conceptualise adoption as a binary outcome, overlooking the structural barriers that shape firms' ability to access, develop skills, and effectively use digital technologies. Moreover, they largely omit external constraints, such as vendor lock-in, monopolistic market structures, and institutional policies, which significantly influence digital adoption trajectories.

Similarly, the information systems and strategic management literature has focused on the benefits of digital technologies, such as innovation, firm performance, and operational efficiency (Dewett & Jones, 2001; Kutzner et al., 2018; Sichoongwe, 2023), assuming that firms have equal opportunities to leverage these advancements. However, disparities in digital capabilities often reinforce existing market inequalities, limiting firms' ability to fully integrate digital tools into their operations. Addressing these gaps requires a framework that moves beyond technology adoption as a single-stage process to one that examines the structural conditions influencing firms' access, skills development, and usage over time. A more dynamic approach can offer deeper insights into the mechanisms driving digital disparities, informing both academic research and policy interventions aimed at fostering equitable technological integration.

Despite significant advancements in digital technologies, persistent inequalities in access, skills, and usage remain prevalent at the firm level. While studies on digital transformation and enterprise technology adoption acknowledge variations in firms’ digital capabilities, this focus opens an avenue for further analysis of the structural mechanisms that perpetuate these disparities. Research by Bach et al. (2013), Lucendo-Monedero et al. (2019), Billon et al.

(2017), Souza et al. (2017), and Shakina et al. (2021) underscores the uneven diffusion of digital tools among firms, highlighting long-standing inequalities in technology integration. Yet, much of the literature prioritises the advantages of digital adoption rather than investigating the underlying barriers preventing equal integration across firms. As digital technologies evolve, the divide has not disappeared but rather expanded to include frontier technologies such as cloud computing, artificial intelligence (AI), and the Internet of Things (IoT). This has widened gaps between firms that successfully integrate these technologies and those that struggle to do so, deepening disparities in digital competitiveness.

These persistent disparities, however, cannot be attributed solely to structural barriers; they are also shaped by the incentives and constraints that influence firms' decisions to adopt technology. While some firms actively integrate digital tools to gain competitive advantages, others encounter financial, organisational, or regulatory challenges that hinder adoption. Understanding the motivations driving digital adoption is therefore crucial for analysing the mechanisms behind digital disparities. Firms pursue digital integration primarily to achieve productivity gains, enhance innovation, and redesign business models (Brynjolfsson & Hitt, 2003; Ciarli et al., 2021; Trischler & Li-Ying, 2023). Digital tools facilitate operational efficiency, automate routine tasks, and optimise industry-specific processes, enabling firms to remain competitive in global markets (Cirera et al., 2022; Galliano & Roux, 2008). Additionally, market pressures, cost reduction strategies, and growth opportunities such as expanding market reach, improving customer engagement, and developing new products serve as strong incentives for firms to invest in digital transformation (Goldfarb et al., 2023; Nicoletti et al., 2020). Institutional interventions, such as tax credits, subsidies, and digitalisation policies, further influence firms' adoption trajectories (Bratta et al., 2020; Dinis et al., 2023).

Moreover, digital technologies operate within monopolistic and oligopolistic market structures, where a handful of dominant firms dictate access, standards, and pricing (Øverby & Audestad, 2021; Petit, 2020). Companies such as AWS, Microsoft Azure, and Google Cloud focus on ensuring the availability of cloud infrastructure. At the same time, digital platform monopolies like Google and Meta regulate data flows and engagement strategies (Costabile et al., 2022). These dominant firms leverage network effects, economies of scale, and proprietary ecosystems to reinforce market dominance, limiting competition and constraining how businesses integrate digital technologies (Conyon et al., 2022). Beyond access, they also influence the availability of training, industry standards, and financial feasibility, making it particularly difficult for SMEs and resource-constrained firms to integrate advanced digital technologies (Senyo et al., 2024). Consequently, digital adoption is not solely shaped by internal firm resources. Still, it is also strategically constrained by the structure of digital markets, where power asymmetries influence the distribution of digital capabilities and deepen firm-level digital divides.

The Resources and Technology Integration Framework (RTIF), adapted from van Dijk's Resources and Appropriation Theory (RAT), provides a comprehensive approach to analysing digital inequalities at the firm level. Unlike individual-focused frameworks, RTIF extends the conceptualisation of access, skills, and usage to firms, integrating these constructs with sector-specific dynamics, institutional support, market structures, and technological disruptions. By doing so, it recognises that firm-level digital transformation is shaped not only by internal factors such as resource availability and strategic capabilities but also by external constraints, including regulatory environments and the dominance of monopolistic and oligopolistic firms.

This chapter develops RTIF to address gaps in existing theories, offering a dynamic and iterative perspective on firm-level digital transformation. Rather than viewing digital adoption as a static or deterministic process, RTIF distinguishes between stable periods of incremental technological integration and punctuated events that accelerate or disrupt adoption trajectories. This dual perspective enables a broader understanding of how firms navigate digital disparities, illustrating how access, skills, and usage interact with market constraints and institutional interventions over time. By incorporating these mechanisms, RTIF provides a stronger foundation for explaining why digital inequalities persist and how firms' positioning within digital ecosystems influences their capacity to integrate emerging technologies.

To guide this theoretical investigation, the chapter addresses the following research questions:

> **RQ4:** *What are the structural and organisational factors that drive disparities in digital technology adoption among firms, and how do these disparities vary across different firm sizes, sectors, and institutional environments?*
>
> **RQ5:** *Through what mechanisms do access, skills, and usage interact in shaping firms' digital trajectories, and how do market structures and institutional policies mediate this process?*
>
> **RQ6:** *How do digital disparities among firms persist or transform over time in response to stable technological conditions and punctuated technological disruptions?*

By answering these questions, the chapter provides a foundation for understanding the structural and dynamic processes that sustain digital inequalities, setting the stage for the broader research framework outlined in this dissertation.

The methodology employed in this chapter follows established guidelines for theory development and adaptation, drawing on the frameworks proposed by Crossler et al. (2018) and Weber (2012), and informed by broader contributions from Dubin (1978), Gregor (2006), and Lakatos (1970). This chapter adopts a structured theory adaptation approach consisting of three key methodological steps: (1) historical contextualisation, (2) conceptual evaluation, and (3) theoretical integration. These steps ensure that the adapted RTIF is theoretically grounded, contextually relevant, and aligned with the study's research objectives. While RAT was originally developed to examine digital inequalities among individuals, this evaluation critically assesses whether its foundational constructs—access, skills, and usage—can be meaningfully reinterpreted to explain firm-level digital disparities. By situating this adaptation within recognised traditions of theory building in the social sciences, the chapter contributes to a more robust understanding of how existing explanatory frameworks can be reconfigured to address emerging empirical challenges.

This chapter is structured to systematically address the theoretical foundation for understanding the digital divide at the firm level. The chapter begins with an introduction to its objectives and research questions, establishing the need for a robust framework to explain disparities in digital technology adoption. The following sections critically evaluate existing theories and frameworks, highlighting their limitations in addressing digital inequalities at the firm level. The chapter then transitions to the conceptual development of a new theoretical framework, building on van Dijk's RAT and integrating insights from institutional and market-structure perspectives. Finally, the chapter concludes by presenting the adapted framework, detailing its constructs and the mechanisms through which digital disparities emerge and persist, thus providing the theoretical foundation for subsequent empirical analysis in the dissertation.

3.2. Literature Review

This literature review explores how digital inequalities emerge within organisations, concentrating on differences in access, skills, and usage. It seeks to connect two areas of research: economic theories of innovation and digital divide studies, by shedding light on how structural, organisational, and institutional factors contribute to uneven digital adoption. Rather than revisiting well-known individual-level debates, the review shifts the lens to firms as the unit of analysis, offering conceptual tools to understand why some organisations progress in digital transformation while others lag behind. In doing so, it lays the groundwork for the framework introduced later in the chapter.

3.2.1. Historical context

The roots of the digital divide at the firm level can be traced to the early history of computing, when access to digital technologies was limited to a small number of large organisations. In the mid-20th century, mainframe computers were prohibitively expensive and technically complex, accessible primarily to government agencies, research institutions, and large corporations with the resources to overcome substantial infrastructure and cost barriers (Larus, 2024; Pick & Sarkar, 2015). The market structure of the time was dominated by monopolistic and oligopolistic dynamics, with firms like IBM leveraging proprietary technologies and economies of scale to maintain market control. These early conditions excluded small and medium-sized enterprises (SMEs), creating the first wave of digital inequality well before the term gained traction in academic discourse.

Empirical studies from the late 1960s and 1980s (e.g., Buckle et al., 1969; Cron & Sobol, 1983; Hunt et al., 1968; Malone, 1985) reinforce this picture of unequal access. Early adopters were overwhelmingly large firms, and while these organisations began integrating computing into core management processes, SMEs faced persistent price and technical barriers. This period established a pattern of exclusion based not only on technological availability but also on firms' structural capacity to adopt and benefit from innovation.

The transition to personal computing in the 1970s and 1980s initially promised to democratise access. However, it also reconfigured rather than dismantled existing market dynamics. New entrants such as Microsoft and Apple capitalised on economies of scope and network effects, creating closed ecosystems that reinforced their dominance. Schumpeter’s (1942) notion of “creative destruction” is useful here: while innovation disrupted incumbent structures, it also produced new monopolistic configurations that limited the broader diffusion of innovation. While dominant players consolidated control over software standards and digital infrastructure, SMEs still faced challenges such as limited compatibility, insufficient internal expertise, and reliance on external vendors.

Meanwhile, on the demand side, firms began integrating personal computers into their operations, but with pronounced variation. Large enterprises quickly adopted PCs to digitise back-office functions and enhance internal efficiencies. In contrast, smaller firms often stayed limited to basic use, mainly for simple accounting or communication because of constraints in internal expertise, staff, and resources. For instance, research based on U.S. small business data from the late 1990s finds that many small firms still did not use computers for core business purposes, creating a clear divide between those digitally engaged and those that were not (Coleman, 2004). This "usage gap" persisted even as internet access improved. Later, the OECD (2021) analysis confirms this: while most SMEs had internet access by the early 2010s, advanced digital use, such as data analytics, remained rare among smaller firms compared to larger ones.

The evolving dynamics of the digital landscape have paved the way for Castells' (1996, 1998) concept of the "network society", where digital infrastructures play a central role in economic and social organisation. Participation in these digital networks presents new opportunities for efficiency and growth, but also introduces new forms of exclusion (Norris, 2001; van Dijk, 2006).

van Dijk's (2005, 2020) RAT builds on Castells' framework by providing a more comprehensive understanding of how digital exclusion occurs. While Castells highlighted the structural importance of network access in the digital economy, van Dijk pointed out that disparities stem not only from a lack of technological access but also from unequal digital skills and limited capacity for effective and productive technology use. Although both scholars primarily focused on individuals and societal groups, their frameworks can also be extended to firms, which face systemic barriers to participating in digital networks. These factors further marginalise businesses from fully engaging in the digital economy, especially when structural constraints hinder their ability to integrate and benefit from digital technologies.

More recently, the emergence of smartphones, cloud computing, and platform-based business models has deepened these inequalities. As Lehdonvirta (2013) notes, digital platforms have become central actors in economic coordination, reshaping industries and concentrating power among firms that control infrastructure, data, and user networks. These "entrepreneurial giants" (Schumpeter, 1942) extend their advantage by setting technology standards and locking users into proprietary ecosystems. For digitally capable firms, such platforms offer opportunities for expansion and optimisation. In contrast, firms with limited digital infrastructure, internal expertise, or capacity to adapt face greater dependence on proprietary systems. These dependencies, such as vendor lock-in or lack of interoperability, compound existing disadvantages, reinforcing a layered structure of digital exclusion.

In sum, the historical trajectory of digital technology adoption among firms has been shaped by cumulative and path-dependent dynamics. Market structures, institutional configurations, and the evolving complexity of technology exacerbated early inequalities in access. Rather than closing over time, these disparities have deepened with each new wave of innovation, transforming observable asymmetries into persistent structural divides that shape which firms succeed in the digital economy and which are left behind.

3.2.2. The digital divide at the individual level

While earlier technological divides existed primarily at the organisational level, the mid-1990s saw the popularisation of the digital divide concept at the individual level as access to personal computers and the Internet became widespread. This individual-level focus shifted attention to disparities in access, skills, and usage (Norris, 2001; Hargittai, 2002; van Dijk, 2005). According to Castillo-Tellez (2023), studies on the digital divide have progressed through multiple phases, mirroring the growth of digital technologies throughout society. Initially, the primary focus of the research was on access disparities. However, it quickly became evident that merely having access to technology was not enough for genuine engagement in the digital economy (van Dijk & Hacker, 2003; Warschauer, 2002).

In the early 2000s, attention shifted to the "second-level digital divide," which focused on differences in digital skills and technology use. van Dijk (2005) and Hargittai (2002) argued that even with access to digital tools, individuals without the necessary skills and knowledge could not fully benefit from them. This shift highlighted a significant gap in digital literacy, with people with lower levels of education and those who are economically disadvantaged lacking the ability to effectively navigate, evaluate, and strategically use digital technology (Laar et al., 2020; van Deursen et al., 2016).

In addition to skills, the usage gap emerged as a critical issue. Even among those with sufficient access and basic skills, inequalities persist in how digital technologies are used (van Deursen & van Dijk, 2014). The usage gap describes the divide between people using the Internet for productive purposes, such as education, seeking information, and career growth, and those mainly using it for entertainment and communication. (Bonfadelli, 2002; van Dijk, 2020; van Dijk & Hacker, 2003; Zillien & Hargittai, 2009). This usage gap partially mirrors the knowledge gap observed with mass media in the 1970s, revealing that unequal usage patterns reinforce existing social inequalities (Hargittai & Hsieh, 2013).

Finally, according to the bibliographic coupling networks from Castillo-Tellez (2023), the third-level digital divide represents the latest wave of research and the current state of research, which extends this understanding to the outcomes of digital participation from different types of use. Disparities in outcomes refer to the unequal social, economic, and cultural benefits that individuals derive from using digital technology. Research by van Deursen and Helsper (2015), Ragnedda (2017, 2018), and Scheerder et al. (2017) illustrates how these differences in usage can either enhance or limit an individual's social and economic capital. However, van Dijk (2020) suggests that outcomes from different types of use may be adverse. While there are concerns about privacy and economic vulnerabilities, others have drawn attention to broader issues such as surveillance (Zuboff, 2019) and ethical concerns (Floridi, 2018).

3.2.3. Conceptual Boundaries: Defining Digital Inequality

Digital inequality, as a concept, has evolved from early concerns about access to a more layered understanding encompassing disparities in skills, usage, and outcomes. Although the term "digital divide" initially portrayed the issue in simple terms, as a straightforward division between those with and without access, more recent approaches acknowledge that digital disparities are multi-dimensional, persistent, and structurally embedded (Hargittai, 2002; Scheerder et al., 2017; van Dijk, 2020; Warschauer, 2002).

This study adopts a firm-level perspective on digital inequality, focusing on how enterprises differ in their ability to access, adopt, and integrate digital technologies. However, conceptualising digital inequality at the firm level requires drawing from multiple disciplinary traditions, each offering distinct but complementary interpretations of the causes, expressions, and consequences of uneven technological uptake.

3.2.4. From Diffusion and Adoption to Structural Gaps

Central to understanding digital inequality is the distinction between diffusion and adoption. The diffusion of innovation, as framed by Rogers (2003) and Griliches (1960), refers to the process through which new technologies spread within and across populations or organisations. In contrast, adoption is the decision and process by which an individual firm integrates a technology into its practices (Hall & Khan, 2003). While classical diffusion models assume a gradual and widespread uptake, recent empirical studies indicate that the adoption of digital technologies is frequently fragmented, with persistent gaps in implementation across regions, sectors, and firm sizes. For instance, Brynjolfsson and McElheran (2016) show that adoption of data-driven decision-making tools in U.S. manufacturing is closely linked to firm size and managerial quality, while Rückert et al., (2020) find that digital technology uptake in the UE firms varies significantly depending on workforce skills, management practices, and organisational characteristics.

Different theoretical traditions provide useful lenses for interpreting these structural gaps. The economics of innovation and evolutionary economics literature examine how such gaps emerge from firm-level heterogeneity in absorptive capacity, routines, and learning trajectories (Cohen & Levinthal, 1990; Malerba, 2005; Nelson & Winter, 1985). Although these frameworks are not specific to digital technologies, they help to understand why certain firms and sectors advance more rapidly in adopting innovation. Meanwhile, the digital divide and ICT for development scholarship (Heeks, 2020) focuses on how these gaps translate into structural disadvantages, particularly when firms lack access to institutional support, digital infrastructure, or skilled personnel. Although some studies cite van Dijk's (2020) framework to emphasise the multidimensionality of digital gaps, their firm-level analyses primarily rely on different theoretical foundations such as innovation diffusion theory, competence-based perspectives, and regional innovation systems to explain ongoing disparities in organisational digital adoption. (Bach et al., 2013; Billon et al., 2017; Shakina et al., 2021).

3.2.5. Reconciling Theoretical Framings of Digital Disparities

In the evolutionary and innovation economics tradition, firm-level differences in adoption and learning are typically understood as structural asymmetries. These reflect variations in capabilities, routines, and absorptive capacities that evolve over time and are shaped by firms' historical and institutional environments (Cohen & Levinthal, 1990; Dosi, 1982; Nelson & Winter, 1985). While these frameworks were developed initially with general-purpose technologies in mind, they offer valuable conceptual insights for understanding the uneven adoption of digital technologies. Classic contributions by Rosenberg (1972) and Dosi (1988) further highlight how technological uncertainty, learning by doing, and institutional lock-ins can delay or fragment diffusion.

While this study adopts the term 'digital inequality' to emphasise persistent, multidimensional, and structural disadvantages in firms' access to, skills in and usage of digital technologies, it recognises that related traditions use varying terminology to describe uneven technological outcomes. For instance, the knowledge economy interprets such persistent differences as 'capability gaps' or 'learning exclusions', disparities rooted in firms' absorptive capacity and their embeddedness in knowledge networks (Cohen & Levinthal, 1990; Lundvall, 2010).

Institutional economics, by contrast, frames persistent disparities as 'structural inequalities' shaped by legal, political, and regulatory institutions that govern access to resources, innovation, and economic opportunities (Acemoglu & Johnson, 2023; Acemoglu & Robinson, 2013; North, 1990). These frameworks offer valuable insights into how institutional arrangements and power structures condition the distribution of capabilities across firms and regions, influencing their potential for technological adoption and digital transformation. These varied terminologies reflect not merely semantic preferences but distinct theoretical assumptions about the causes, persistence, and implications of technological disparities. Recognising these differences allows for a more precise and comprehensive understanding of how digital inequality operates across organisational contexts.

In contrast, digital divide literature interprets persistent gaps in digital technology adoption as structural inequalities, not merely reflecting diversity in trajectories, but systemic disadvantages that shape access to opportunity and reinforce exclusion (Selwyn et al., 2001; van Dijk, 2020). When this perspective is extended to organisational contexts, different studies show that digital disparities can limit firms' competitiveness, innovation capacity, and integration into digital ecosystems (Bach et al., 2013; Billon et al., 2017; Shakina et al., 2021). These perspectives emphasise the influence of institutional conditions, workforce skills, and policy support on shaping firms' ability to adopt and effectively utilise digital technologies (Hanna, 2016).

The current study seeks to integrate these perspectives to develop a more thorough understanding of digital disparities at the firm level. Persistent asymmetries in firm capabilities and learning pathways, when compounded by systemic barriers, can transform into lasting forms of digital inequality. In this sense, incomplete diffusion may not function as a neutral or temporary deviation, but rather as a process through which structural disparities in technological adoption are sustained and deepened over time. This perspective draws on insights from sectoral innovation systems and technological regimes (Malerba & Orsenigo, 1995), as well as empirical research showing how institutional and organisational constraints hinder the digital integration of firms (Srivastava & Shainesh, 2015). While the conceptual terminology varies from asymmetries and capability gaps to structural inequalities, these frameworks converge in recognising that persistent digital disparities are neither random nor temporary. Instead, they reflect multi-layered processes grounded in economic, organisational, and institutional dynamics. This conceptual clarification of digital disparities, as framed by different traditions, sets the stage for examining the structural conditions under which digital technologies are adopted. The following section explores how the dynamics of supply and demand in digital markets shape firm-level adoption and how these structures contribute to the persistence of the inequalities discussed above.

3.2.6. Structural Conditions of Digital Technology Adoption

The market for digital technologies is characterised by distinct dynamics in supply and demand, shaped significantly by the structural features of the digital economy. On the supply side, monopolistic and oligopolistic market structures dominate. Large firms such as Facebook, Google, and Amazon Web Services (AWS) have established de facto monopolies in critical digital segments by leveraging strong network effects, lock-in mechanisms, and economies of scale (Øverby & Audestad, 2021). These dynamics create high barriers to entry for smaller competitors, as market dominance is reinforced by the increasing returns associated with expanding user bases. Moreover, many digital firms operate multisided platforms that simultaneously serve consumers, advertisers, and developers. For example, social media platforms combines monopolistic control over social networking with oligopolistic dynamics in digital advertising, profiting from cross-side network effects that amplify its market power (Rietveld & Schilling, 2024). The concentration of supply within a few dominant actors raises structural concerns, as these firms influence pricing models, technology standards, and data governance regimes that shape the broader digital environment.

Beyond market concentration, the structural characteristics of digital ecosystems also influence demand-side disparities. In particular, the distinction between proprietary (closed) and open-source (open) ecosystems shapes firms' opportunities to access, adapt, and build upon digital technologies. Proprietary platforms such as Microsoft Azure or Apple's iOS often operate within tightly controlled environments, restricting interoperability and reinforcing vendor lock-in, which can inhibit smaller firms from customising or repurposing technologies to their specific needs (Bessen, 2006; West, 2003). In contrast, open-source ecosystems, such as Linux, Apache, and Python, offer greater flexibility, community-driven innovation, and lower entry costs, especially for resource-constrained enterprises. However, recent research suggests that open-source ecosystems are increasingly becoming platform-based, evolving into modular, large-scale environments that depend on complex socio-technical dynamics and dense developer networks (Müller et al., 2019). These *platform-based open source software ecosystems* require significant coordination, standardisation, and technical expertise to navigate effectively. As such, the ability to leverage open ecosystems also presupposes internal skills and absorptive capacities (Feller et al., 2005), which are themselves unequally distributed across firms. The coexistence of proprietary and open systems, each with distinct implications for entry, control, and innovation, adds a further layer to the structural dynamics shaping digital adoption. Their strategic competition intensifies network effects and subtly influences the conditions under which firms on the demand side can adopt and adapt digital tools.

On the demand side, persistent disparities in digital technology adoption are evident across firm size, sector, and region. These disparities shape not only whether organisations, including SMEs, large firms, and public bodies, gain access to digital tools, but also how they adopt and integrate them into operational and strategic processes. Larger enterprises, typically equipped with greater financial, technical, and managerial resources, are more likely to adopt advanced technologies such as artificial intelligence, cloud infrastructure, and the Internet of Things (Conyon et al., 2022). In contrast, SMEs often face resource constraints, limited internal expertise, and weaker institutional support systems, which hinder their ability to engage in meaningful digital transformation (Cusolito et al., 2020; Henderson, 2020). These firm-level differences reflect what Malerba and Orsenigo (1995) describe as persistent asymmetries in innovation capabilities.

While this study adopts a demand-side perspective, viewing firms as users rather than producers of technology, it is essential to recognise that supply-side dynamics indirectly shape adoption conditions. These structural conditions constrain how firms engage with digital tools and shape broader adoption patterns (Øverby & Audestad, 2021; Wan et al., 2023)

In this context, the most visible manifestations of digital inequality emerge on the demand side, where firms diverge in their ability to access, develop, and strategically use digital technologies. Analysing adoption through this lens highlights the uneven accumulation of digital capabilities, particularly among SMEs and peripheral firms, and underscores the need for targeted inclusion strategies. To better understand the roots and persistence of these disparities, the following section turns to economic perspectives that explain how structural, organisational, and institutional dynamics shape the distribution of technological adoption across firms and sectors.

3.2.7. Economic Perspectives on Digital Disparities

Digital technologies are not adopted uniformly across firms, sectors, or regions, as evidenced by multiple empirical studies that document persistent disparities in digital adoption across firm types, industries, and national contexts (Berlingieri et al., 2020; Billon et al., 2017; Brynjolfsson & Hitt, 2003; Forman et al., 2012; Shakina et al., 2021). Understanding why such disparities persist requires grounding the analysis in established economic theories that explain the conditions under which technology is created, diffused, and used. This section synthesises six influential economic traditions: neoclassical, endogenous growth, knowledge economy, evolutionary, Schumpeterian, and institutional economics, to clarify how each interprets the uneven uptake of technology and how their insights contribute to the conceptualisation of digital inequality.

3.2.7.1. Neoclassical Growth Theory

Neoclassical growth theory, as developed by Solow (1956) and Swan (1956), treats technological progress as an exogenous driver of economic growth. In this framework, technology is considered a public good that is freely available and universally accessible across companies and regions. Adoption is assumed to occur automatically once a technology becomes available, with disparities in uptake seen as temporary market imperfections. Over time, the model forecasts convergence in productivity and innovation performance, assuming that all firms respond similarly to economic incentives.

Early economic models of diffusion, such as those by Griliches (1960) and Mansfield (1961), assume that firms act as rational agents, adopting new technologies based on profit expectations and access to improving information. These models, grounded in neoclassical economics, treat diffusion as the sum of individual optimising decisions under ideal market conditions. While helpful in understanding early patterns of technology uptake, they struggle to explain persistent digital adoption gaps across firms and regions. Although Griliches (1960) acknowledged time lags, the broader neoclassical framework underestimates the impact of structural constraints, such as uneven access to capital, human skills, and infrastructure, on firm-level outcomes. Therefore, while foundational, these models offer limited insight into long-term digital inequalities. This perspective remains mainly focused on the **demand side**, portraying firms as technology adopters who respond to incentives in a frictionless market.

3.2.7.2. Endogenous Growth Theory

Endogenous growth theory, advanced by Romer (1990) and Lucas (1988), rejects the neoclassical assumption of exogenous technological progress. Instead, it posits that innovation results from deliberate investments in research and development (R&D), human capital, and knowledge production. Technological change is thus an outcome of internal economic processes, shaped by the capacity of firms and regions to generate, absorb, and apply new knowledge. Unlike the convergence predicted in neoclassical models, endogenous growth frameworks permit persistent divergence in innovation outcomes across firms and regions.

This perspective provides a more nuanced lens for interpreting digital inequalities. Firms with greater resources, higher-skilled personnel, and stronger R&D capabilities are more likely to access and integrate advanced digital technologies. Cohen and Levinthal's (1990) concept of absorptive capacity, the firms' ability to recognise, assimilate, and exploit external knowledge, illustrates how disparities in internal capabilities affect technology adoption. Pavitt (1984) and Maskus (2000) further highlight how intellectual property regimes and investment patterns shape access to innovation. In the context of digitalisation, this suggests that uneven adoption is not a temporary lag, but a consequence of structurally embedded differences in firms' innovation capacity and strategic orientation. While focusing on **supply-side innovation drivers,** such as R&D and human capital, endogenous models also highlight **demand-side constraints**, as adoption depends on internal capabilities and investment incentives.

3.2.7.3. The Knowledge Economy

The knowledge economy perspective conceptualises technology as an outcome of cumulative learning, institutional interactions, and embedded organisational capabilities. Rather than focusing solely on R&D or formal education, this framework highlights the centrality of tacit knowledge, networked learning, and collaborative innovation processes (David & Foray, 2003; Lundvall, 1992). Firms operate within systems of knowledge exchange, such as regional innovation systems or global value chains, where their position and connectivity shape their access to new technologies and practices (Cooke, 2001; Foray & Steinmueller, 2003).

In this view, digital inequalities emerge not only from differences in investment but also from 'capability gaps', disparities in firms' ability to learn, adapt, and participate in knowledge-intensive environments (Cohen & Levinthal, 1990; Lundvall & Lorenz, 2012). This perspective aligns with earlier insights from Rosenberg (1984) on 'learning by using' and von Hippel's (1988) concept of user-driven innovation, both of which suggest that firms adapt and refine technologies based on experiential knowledge and situated needs. Learning exclusions, especially for SMEs or peripheral firms, stem from limited exposure to best practices, weak institutional support, and disconnection from innovation networks. Unlike endogenous growth theory, which emphasises formal inputs, the knowledge economy underscores relational and systemic factors that mediate digital transformation. This perspective blurs the line between

supply and demand, as firms are both **users and co-creators** of technology within networks and systems of knowledge exchange.

3.2.7.4. Evolutionary Economics

Evolutionary economics provides an alternative to optimisation-based models by emphasising bounded rationality, historical contingency, and firm-specific routines as drivers of technological change. Rather than adopting the most efficient technologies available, firms evolve through experimentation, learning by doing, and incremental adjustments shaped by past decisions (Dosi, 1988; Nelson & Winter, 1985). Technological adoption is path-dependent, meaning that early investments, sunk costs, and organisational routines constrain future choices, potentially locking firms into suboptimal trajectories (Cantner & Vannuccini, 2016).

From this perspective, observable digital disparities are framed as structural asymmetries. Firms differ not only in their access to digital tools but also in their internal capacity to experiment, adapt, and absorb new knowledge. Rosenberg (1972) and Malerba (2002) have demonstrated how differences in learning dynamics and technological regimes can result in persistent gaps in innovation adoption. These asymmetries are not transient but evolve over time, reinforcing inequalities between firms with adaptive capabilities and those constrained by institutional or organisational inertia.

Adding further depth to this analysis, Metcalfe (1994) argues that competition itself operates as a selection process shaped by increasing returns. Firms that gain early advantages, whether through resource endowment, organisational learning, or successful experimentation, are more likely to be selected and retained in the market, while others are gradually excluded. This evolutionary selection mechanism explains why digital inequalities are not self-correcting: rather than converging, firm trajectories often diverge due to positive feedback loops and cumulative advantage. Evolutionary economics thus offers a robust framework for understanding why digital technologies diffuse unevenly, even in contexts where access is theoretically available. It emphasises firm-level learning, routines, and adaptation often associated with the demand side of innovation, while also accounting for how technological regimes, selection environments, and industry dynamics shape the pace, direction, and supply of innovations.

3.2.7.5. Schumpeterian Economics

Schumpeterian economics, rooted in Schumpeter's (1942) work, views innovation as a disruptive process of "creative destruction," where new technologies replace existing ones, leading to the reconfiguration of markets, industries, and firm hierarchies. Within this framework, technological change is inherently uneven, resulting in winners and losers. Firms that successfully innovate gain temporary monopoly advantages, while those unable to adapt risk obsolescence. Innovation is thus both a source of economic dynamism and a driver of structural inequality.

This lens is particularly relevant in the digital economy, where rapid technological shifts disproportionately benefit early adopters and dominant platforms. Aghion and Howitt (1992) formalise this through models showing how innovation races and market selection mechanisms lead to concentration. Levinthal (1998) and Hanusch and Pyka (2007) further emphasise that a firm's survival depends on its capacity to adapt to changing technological frontiers. While Schumpeter's original framework is more attuned to the supply side, focusing on firms that produce and deploy innovations, its implications extend to the **demand side** as well, particularly for organisations that must respond to disruptive shifts in their technological environment. Digital adoption gaps, therefore, reflect deeper dynamics of technological competition and market restructuring.

3.2.7.6. Institutional Economics

Institutional economics shifts the focus from market mechanisms to the formal and informal rules that structure economic behaviour. Pioneered by North (1990), this tradition posits that institutional laws, norms, property rights, and governance structures determine the incentives and constraints that shape innovation and technological diffusion. Rather than treating access to technology as automatic or evenly distributed, institutional economics emphasises how political and legal arrangements condition who can access, adopt, and benefit from technological change.

Institutional economics provides a critical perspective for understanding digital disparities, mainly by highlighting the importance of formal and informal rules in shaping technological adoption. Institutions such as competition law, education systems, digital infrastructure policies, and intellectual property regimes influence how digital capabilities are distributed across firms and regions. While North (1990) originally focused on how institutions structure long-term economic development, more recent work by Acemoglu and Robinson (2013) refines this view by distinguishing between inclusive institutions that foster widespread innovation and extractive institutions that concentrate benefits among dominant actors. Applied to digital transformation, this framework suggests that disparities in firm-level adoption are not merely technical or market-based but are also shaped by institutional access, incentives, and constraints.

Empirical studies in digital governance and ICT policy further reinforce this perspective. Research by Hilbert (2011) and Hanna (2016) highlights how regulatory gaps, insufficient public investment, and fragmented policy frameworks contribute to persistent digital divides, particularly affecting SMEs and firms in peripheral regions. Institutional arrangements, therefore, do not simply facilitate or hinder adoption in a passive sense; they actively structure the pathways through which technologies are developed, disseminated, and appropriated. This tradition thus cuts across both supply and demand dynamics, offering a comprehensive explanation for how institutions shape the conditions under which firms engage with digital technologies.

3.2.7.7. Synthesis and Conceptual Bridge

Despite their diverse assumptions and terminologies, the economic traditions reviewed above converge on three key dimensions that shape firms' engagement with digital technologies: access to infrastructure and technological tools, the development and application of digital skills, and the practical usage of these technologies for strategic or operational purposes. While these dimensions are not always explicitly defined in economic theory, they appear as recurring mechanisms across models, from absorptive capacity and learning routines to institutional access constraints and network embeddedness. These constructs—access, skills, and usage—provide a conceptual bridge between economic perspectives on technological change and the analytical framework developed in the subsequent sections, where they will be formalised and integrated into a theory of firm-level digital inequality.

3.2.8. Theoretical Frameworks for Understanding Digital Inequality

Technological adoption and integration among firms are complex processes shaped by both structural and organisational dynamics (Ciarli et al., 2021; Figueiredo et al., 2021). While economic theories offer vital macro-level insights into technological change and diffusion, understanding the observable differences in digital adoption, especially among firms of various sizes and sectors, requires additional analytical perspectives. Information systems and strategic management theories provide such viewpoints, allowing for a more detailed examination of how digital technologies are accessed, integrated, and embedded within business operations. This section critically reviews four prominent frameworks DOI, TOE, the Resource-Based View (RBV), and Dynamic Capabilities (DC) to assess their explanatory power in accounting for firm-level heterogeneity in digital integration.

3.2.8.1. Diffusion of Innovations

The DOI model, introduced by Rogers (2003), conceptualises the spread of new technologies by focusing on how innovations are communicated and adopted over time. It identifies five key attributes influencing adoption decisions: relative advantage, compatibility, complexity, trialability, and observability. It also classifies adopters along a temporal continuum from innovators to laggards. Widely used across disciplines, DOI remains fundamental in explaining patterns of innovation adoption. Nonetheless, DOI has faced significant critique for its linearity and underlying assumption of inevitable adoption. Fichman (2000) contends that DOI underestimates the structural and organisational frictions that may stall or distort the diffusion process. MacVaugh and Schiavone (2010) highlight how institutional inertia, technological complexity, and learning requirements can severely constrain adoption, particularly in organisational contexts. More recently, Lyytinen and Damsgaard (2001) have argued that innovation adoption is often recursive and subject to iterative redefinition, a nuance that DOI largely overlooks. These critiques suggest that DOI, while informative at a macro level, provides limited guidance for diagnosing unequal or incomplete digital uptake within and across firms.

3.2.8.2. Technology–Organisation–Environment Framework

The TOE framework (Tornatzky et al., 1990) advances a more structured view of adoption by identifying three analytical domains: the technological context (e.g., perceived benefits or complexity of new tools), the organisational context (e.g., internal readiness, firm size, managerial support), and the environmental context (e.g., competition, regulation, institutional support). This tripartite approach enables empirical mapping of adoption patterns by linking them to firm-specific and contextual variables. TOE has been particularly influential in studies examining cross-sectoral or regional variation in digital technology uptake (Baker, 2011; Zhu & Kraemer, 2005).

While the TOE framework has demonstrated empirical utility across diverse organisational settings, its explanatory scope remains limited in some respects. Scholars have observed that TOE tends to conceptualise adoption as a relatively static event, offering limited insight into the processes through which firms develop digital capabilities over time (Oliveira et al., 2014). As Baker (2011) notes, the framework underrepresents feedback loops and learning mechanisms that shape the longer-term trajectory of digital transformation. Moreover, TOE's treatment of firm heterogeneity often focuses on broad contextual variables, overlooking finer-grained dynamics of resource mobilisation or internal capability development. These limitations do not negate the value of TOE as a structural diagnostic tool, but rather indicate areas where complementary frameworks may be needed to address questions of inequality and long-term capability building.

3.2.8.3. Resource-Based View and Dynamic Capabilities

The Resource-Based View (RBV) and the Dynamic Capabilities (DC) framework offer more granular insights into how firms' internal characteristics influence strategic outcomes. RBV posits that sustainable competitive advantage stems from possession of valuable, rare, inimitable, and non-substitutable (VRIN) resources (Barney, 1991). Although initially developed within the broader field of strategic management, the Resource-Based View (RBV) has been expanded to explain firm-level differences in digital transformation by conceptualising digital assets such as ICT infrastructure, software systems, and digital skills as strategic resources that meet the VRIN criteria. (Bharadwaj, 2000; Wade & Hulland, 2004). These resources are not evenly distributed across firms, resulting in structural asymmetries that shape the capacity to adopt and benefit from digital technologies. Recent studies reaffirm that differences in digital resource configurations are key explanatory variables in determining the extent and effectiveness of digital transformation processes, especially when such resources are embedded within organisational routines and capabilities (Osarenkhoe & Fjellström, 2021; Willie, 2024). In this sense, RBV provides a conceptual foundation for interpreting digital inequalities not as isolated outcomes but as the result of enduring disparities in access to and control over strategic digital assets.

However, RBV's static orientation has been a point of criticism, particularly in fast-changing environments where technological trajectories evolve rapidly (Priem & Butler, 2001). The DC framework addresses this limitation by focusing on firms' abilities to sense opportunities, seize them through organisational alignment, and reconfigure resources accordingly (Teece, 2007; Teece et al., 1997). This perspective emphasises the importance of strategic agility in navigating digital transformation and has proven particularly relevant in empirical studies examining innovation and digitalisation under conditions of environmental turbulence (Al-Moaid & Almarhdi, 2024; Warner & Wäger, 2019).

While the RBV and DC frameworks offer valuable insights into how firms leverage internal resources and adapt to technological change, they often remain abstract when applied to contexts characterised by resource constraints or institutional misalignment. These theories emphasise *what* capabilities matter for competitive advantage, but provide limited guidance on *how* such capabilities are developed, especially in firms with low digital readiness. This gap becomes particularly salient in the case of SMEs, where digital transformation requires not only strategic intent but also practical mechanisms for resource mobilisation, skill formation, and external support. As such, while RBV and DC remain foundational to understanding firm-level heterogeneity, their explanatory power may be limited in accounting for the structural and procedural challenges that underlie digital disparities among less digitally mature firms.

3.2.8.4. Limitations of Existing Frameworks

Taken together, these theories provide essential, but partial, explanations of digital technology adoption. DOI and TOE are effective in identifying adoption patterns and contextual influences, often focusing on single adoption events or the spread of technologies across populations. Their primary contributions are oriented toward explaining when and why technologies are adopted, rather than how they are internally integrated and operationalised over time. Meanwhile, RBV and DC shift the focus inward, offering insights into how firms utilise internal resources to create a strategic advantage. However, these frameworks have traditionally addressed questions of performance and competitiveness, rather than inequality. When viewed through the lens of digital inequality, structural disparities become more visible not only in terms of whether firms adopt digital technologies, but also in how and when they do so. These differences affect not only initial uptake but also the progression toward a competitive advantage and the broader diffusion of technology across a population. Factors such as unequal access to resources, varying levels of internal capabilities, and divergent usage patterns contribute to delayed or incomplete diffusion trajectories, thereby reinforcing disparities in digital integration. These observations suggest that existing theories, while robust in their own domains, require complementary perspectives to fully account for the layered and interdependent nature of digital transformation across heterogeneous firms.

3.2.9. Positioning the Resources and Technology Integration Framework

Although firms have long been studied in innovation diffusion and digital adoption research, the concept of the digital divide, especially its multi-dimensional structure of access, skills, and usage, has rarely been explicitly applied to analyse disparities between firms. Instead, organisational research has traditionally concentrated on the role of digital capabilities in influencing performance outcomes. (Bharadwaj, 2000; Sambamurthy et al., 2003), while adoption models such as DOI and TOE have explained how contextual and organisational variables condition uptake (El-Haddadeh, 2020; Steiber et al., 2020). These frameworks are analytically valuable, yet they typically treat adoption as a discrete decision or outcome, rather than a recursive and uneven process of capability building.

In parallel, a growing body of research has identified persistent gaps in technology adoption and digital competencies across firms (Bach et al., 2013; Billon et al., 2017; Lucendo-Monedero et al., 2019; Shakina et al., 2021). These studies increasingly highlight digital disparities in terms of access, skills, and usage, but a fully unified theoretical framework remains underdeveloped. This is partly due to the limited availability of granular, firm-level data and the relatively recent shift in focus from individual to organisational digital divides. As a result, while significant conceptual and empirical contributions exist, the literature remains somewhat fragmented in explaining how and why digital inequalities persist across sectors, regions, and firm sizes.

The research gap lies not in the absence of firm-level studies on digital transformation, but in the lack of a framework that systematically interprets these findings through the lens of the digital divide. The RTIF addresses this need by explicitly modelling how disparities in access, skills, and usage co-evolve and shape differentiated digital outcomes. While frameworks such as RBV, DC, and TOE offer valuable insights into resource advantages, capability formation, and contextual factors influencing adoption, they are not primarily designed to explain the persistence of structural disparities across firms, sectors, and regions.

RTIF complements and extends these perspectives by shifting the analytical focus from competitive performance or adoption enablers to the underlying conditions that constrain or enable digital integration. It conceptualises digital transformation as a cumulative and interdependent process, where firms' trajectories are shaped by recursive interactions between their resource base, capability development, and usage practices. This framing is particularly relevant for SMEs and firms in peripheral regions, where digitalisation is not only a question of strategy but of overcoming tangible constraints in infrastructure, skills, and institutional support. In capturing these dynamics, RTIF offers a theoretically grounded and empirically applicable model for analysing digital inequalities and guiding inclusive policy design.

3.3. Methodology

This methodology follows a structured theory adaptation approach, aiming to repurpose van Dijk's (2005, 2020) RAT for application in organisational contexts. In line with Weber's (2012) and Crossler et al.'s (2018) criteria for evaluating and adapting theories in information systems, the adaptation proceeds through three stages: contextual evaluation, assumption alignment, and structural assessment. These stages draw from established theory-building frameworks (e.g., Dubin, 1978; Gregor, 2006) and emphasise the importance of conceptual clarity, internal coherence, and domain relevance.

As Gregor (2006) argues, Type II theories aim to explain "how" and "why" phenomena unfold, rather than to predict or prescribe. RAT belongs to this category, offering an explanatory account of digital inequalities based on the interaction of motivational, material, and skill-based resources. This study extends the explanatory utility of RAT by adapting it to the organisational level, where disparities in access, skills, and usage persist but are shaped by a different set of institutional and technological dynamics.

To justify this theoretical adaptation, we draw on foundational work in the philosophy of science. According to Lakatos (1970), theory evolution involves progressive problem shifts within a research programme. Adaptations are legitimate when they increase explanatory power. Similarly, Elster (1989) and Mäki (2001) advocate for theory construction grounded in mechanisms and microfoundations, enabling a better fit with observed organisational realities. By preserving RAT's core constructs while contextualising them for firms, this adaptation aligns with these principles of theory development.

This study narrows its focus to the first and second levels of the digital divide (access, skills, and usage), excluding outcome-level disparities due to data limitations and scope constraints. While van Dijk's (2020) extended model includes outcomes such as economic and socio-cultural benefits, firm-level datasets rarely provide consistent metrics for such results. Instead, this research targets the mechanisms through which foundational digital capacities affect firms' technological integration and competitiveness issues central to current debates in digital transformation and organisational inequality (Cirera et al., 2022).

The rationale for adapting RAT also stems from its empirical and conceptual limitations. Although RAT has been widely applied to analyse digital disparities at the individual level (e.g., Lamberti et al., 2021; Toudert, 2016; van Deursen et al., 2021), it falls short in addressing organisational dynamics. Specifically, it does not sufficiently account for firm-level contingencies such as regulatory frameworks, path dependency, or industry-specific constraints. Addressing these gaps requires a more context-sensitive approach, one that captures how firms undergo digital transformation under conditions of bounded rationality and structural asymmetries. These concerns align with core insights from evolutionary economics and theories of path dependence (Dosi, 1988; Nelson & Winter, 1985).

By anchoring the adaptation in established theory-building methodologies and aligning it with the empirical specificities of organisational contexts, this study not only extends the explanatory power of RAT but also contributes to a broader research programme on digital inequality in firms. This approach enhances the theory's internal coherence, expands its domain of applicability, and offers a structured lens through which to examine how digital infrastructures, competencies, and practices shape differential outcomes across organisational settings.

3.3.1. Historical context and assumptions

This stage aims to place the RAT within its historical and theoretical origins. Table 5 presents a concise historical context drawn from the literature review, situating the RAT within its theoretical background. By tracing the evolution of digital inequalities for individuals and the progression of how these inequalities are multidimensional.

Theory Part	Evaluation of the reference theory van Dijk's RAT
Historical Context	The digital divide originated with disparities in physical access to computers and the internet during the late 20th century, primarily influenced by income, education, and geographic location (van Dijk, 2012, 2020). Early research focused on the first-level digital divide, highlighting gaps in infrastructure and connectivity (Norris, 2001). As access improved, particularly in developed countries, the divide evolved into a second-level digital divide, characterised by inequalities in digital skills and usage patterns (Hargittai, 2002; Hargittai & Hinnant, 2008; Zillien & Hargittai, 2009). This shift reflects broader socioeconomic structures, where certain groups, such as those with lower educational attainment or income, struggle to utilise digital technologies effectively. These disparities have profound implications for participation in higher-value digital activities, such as education and economic engagement, underscoring the systemic inequalities that perpetuate digital exclusion and reinforce societal inequities (Ragnedda, 2018; van Dijk, 2012).
Theoretical Background	The RAT integrates multiple perspectives to explain the digital divide as a dynamic, multi-stage process. Drawing on technology acceptance theories such as the Theory of Planned Behaviour (Ajzen, 1991) and the Technology Acceptance Model (Davis, 1989), RAT emphasises motivation, perceived usefulness, and ease of use in technology adoption. It also incorporates materialist perspectives,

	particularly Bourdieu's (1983) capital theory and Giddens' (1991) structuration theory, to highlight how economic, social, cultural, and temporal resources influence disparities. The socio-cultural perspective, informed by Weberian sociology (Weber, 1978) and domestication theory (Silverstone & Mansell, 1996), underscores the role of social norms, lifestyles, and cultural meanings in shaping technology use. Additionally, the relational perspective (Wellman & Berkowitz, 1997) addresses inequalities arising from categorical distinctions and network dynamics.

Table 5: Historical Context and Theoretical Grounding of van Dijk's RAT.

The framework's foundational assumptions, outlined in Table 6, provide further explanation of the conceptual underpinnings of the RAT. These assumptions establish the principles guiding its application, such as the systemic nature of digital inequalities and the relational dynamics that perpetuate them. These foundational elements are pivotal for adapting the RAT to firm-level analyses and ensuring its applicability in organisational contexts.

Assumption	**Description**	**Implications**
Digital Inequalities as Systemic	Digital inequalities are deeply embedded in systemic social structures, shaped by relational factors such as education, labour market positions, and age, rather than being solely individual issues.	Highlights the persistent influence of structural barriers that perpetuate digital divides, necessitating policy interventions and systemic solutions to address these disparities.
Relational Nature of Inequality	Inequality arises from categorical differences and interactions between structural factors, going beyond individual-level attributes.	Emphasises the importance of addressing digital divides through multi-dimensional strategies that account for societal and institutional dynamics, rather than isolated interventions.
Resource Dependency	Access to resources e.g. temporal, material, mental, social, and cultural are assumed to be a critical mediator for digital inclusion.	Unequal distribution of resources acts as a systemic barrier to digital inclusion. Individuals with limited resources face compounded challenges, as resource disparities intersect with systemic inequalities.
Linear Progression	Digital inclusion follows a staged progression: motivational access → physical access → digital skills → usage access, assuming a structured pathway to inclusion.	While offering a clear framework for inclusion, this assumption may oversimplify digital adoption's iterative and non-linear nature, limiting its application to complex, real-world scenarios.
Exacerbating Role of Technology	Digital technologies, due to their inherent complexity and cost, are assumed to deepen existing inequalities, especially for	Highlights the need for targeted interventions to address the affordability and accessibility challenges posed by advanced technologies, particularly for vulnerable populations, to prevent widening divides.

	marginalised or under-resourced groups.	
Prerequisite of Digital Access	Access is considered foundational for participation in economic, social, and political life, with motivational access identified as the first step in bridging the digital divide.	Unequal access reinforces socio-economic disparities, excluding individuals and groups from opportunities in modern society. Incorporating motivational access, physical access, development of skills and meaningful usage.
Dynamic Interaction of Constructs	Although initially presented as linear, the framework allows for dynamic interactions and feedback loops between access, skills, and usage, acknowledging that changes in one construct influence others.	Recognising and incorporating dynamic processes can improve the explanatory power of the framework. Acknowledging the third-level divide further highlights how outcomes of digital participation recursively influence disparities in earlier stages, demonstrating a cyclical mechanism of inequality perpetuation.

Table 6: Key Assumptions of van Dijk's RAT.

3.3.2. Rhetorical analysis

The rhetorical analysis of the RAT provides a critical lens to evaluate its contributions to digital divide literature and its applicability to organisational contexts. This analysis employs Locke and Golden-Biddle's (1997) dual lenses of intertextual coherence and problematisation to assess the theory's strengths and limitations. Intertextual coherence situates RAT within the broader theoretical discourse, demonstrating how it synthesises existing arguments about digital disparities, advances them through its structured framework of access, skills, and usage, and highlights unresolved tensions in the literature. However, problematisation reveals critical limitations when RAT is applied beyond individual contexts.

3.3.3. Intertextual coherence

The RAT provides a foundational framework for understanding individual-level digital inequalities by highlighting the relational perspective behind the primary constructs such as motivational access, physical access, digital skills, and usage (Ragnedda & Muschert, 2013). RAT achieves synthesised coherence by integrating mediating resources, including material, cultural, and social factors, to explain how disparities develop across demographic and positional categories such as age, education, and labour position (van Dijk & Hacker, 2003). This integration bridges earlier fragmented approaches that often focused only on access or overlooked other dimensions, such as skills and usage (Hargittai, 2002; Zillien & Hargittai, 2009).

RAT also demonstrates progressive coherence by advancing beyond descriptive studies (van Dijk & Hacker, 2003). The staged progression within the model systematically explains the sequential development of digital inclusion. By incorporating resource mediation into this progression, RAT enhances theoretical clarity in showing how inequalities persist over time (van Dijk, 2020). However, the framework reveals non-coherence when applied directly to organisations, as it does not account for structural and market factors, or external forces such as institutions with regulatory frameworks and technological change.

3.3.4. Problematisation

The problematisation of RAT highlights critical gaps that must be addressed for its application to organisational contexts. First, incompleteness emerges from the framework's individual-level focus, which excludes firm-level factors such as size, structure, and strategic positioning. Second, inadequacy lies in RAT's omission of external forces such as institutions and market dynamics that can influence digital technology adoption. Finally, incommensurability arises from the misalignment of constructs, such as personal categories, when applied to firms, requiring reconceptualisation rather than direct application. By addressing these dimensions, the adaptation of RAT not only resolves these issues but also advances its applicability as a middle-range theory for understanding organisational digital disparities.

3.3.5. Parts assessment

This stage evaluates the structural components of RAT to identify areas for adaptation. This section begins with an evaluation of constructs, associations, states, and events using Crossler et al.'s (2018) guidelines (Table 7). It then transitions to assessing contextual constructs, such as firm-level heterogeneities and external factors (Table 8, which provide the backdrop for understanding disparities in digital adoption. Finally, primary constructs, including access, skills, and usage (Table 9), are analysed in detail to show how they were redefined to suit organisational contexts.

Table 7 evaluates RAT's structural components, focusing on its constructs, associations, states, and events. Constructs represent core attributes, such as access, skills, and usage, while associations describe the relationships between these constructs. States outline all possible combinations of construct values, and events represent transitions between these states, providing a foundation for analysing the framework's applicability to organisations.

Theory Part	Assessment of van Dijk's Resources and Appropriation Theory
Constructs	van Dijk's framework includes both **primary constructs**, such as motivational access, physical access, digital skills, and usage, and **contextual constructs**, such as personal categories, positional categories, and resources. The primary constructs define the stages of digital access, while the contextual constructs explain the underlying factors that shape disparities in access. For example, personal categories (e.g., age, gender) and positional categories (e.g., labour market roles, education) provide the socio-structural context influencing access, skills, and usage. Additionally, resources such as material (income), social (network support), and cultural (digital literacy norms) act as mediators in the appropriation of technology. For a comprehensive evaluation, all these elements are considered as constructs because they collectively delineate the domain of the theory and offer explanatory power for the phenomena it addresses.
Associations	The framework identifies associations between constructs, such as the causal relationships between categorical inequalities (personal and positional) and the unequal distribution of resources, which in turn impact stages of digital access: such as **motivation → access → skills → usage**, suggesting a sequential flow. These associations are hierarchical and directional, suggesting that disparities in categories like education or employment lead to differences in resources, which then affect motivation, access, skills, and usage. While critiques of the sequential model argue that it oversimplifies interactions by assuming one-way causality and overlooking feedback loops, the structured progression provides a practical and empirically grounded explanation of digital disparities. Feedback loops, while theoretically appealing, may lack the predictive clarity offered by the sequential model, particularly in resource-constrained or systemically unequal environments where progression depends heavily on foundational stages being addressed first.
States	States within the framework represent the conditions individuals or groups experience at various stages of digital access and participation. These states capture specific points along the spectrum of digital inclusion, such as being 'motivated but lacking physical access' or 'having access but insufficient digital skills.' By defining these states, the framework provides a structured way to diagnose where individuals are situated in their digital integration journey. It assumes orderly transitions between states, following a sequential progression motivation precedes access, which leads to skills, culminating in usage.
Events	Events in the framework represent the transitions or changes between states, such as progressing from being unmotivated to motivated, acquiring physical access, or developing new digital skills. These events are triggered by both external factors such as policy interventions, technological advancements, or market dynamics and internal conditions, including increased awareness of technology's benefits or a shift in resource availability. Positive events, like subsidised internet access or community-driven digital literacy programmes, can propel individuals or firms through the stages of digital inclusion. Conversely, negative events, such as economic downturns, technological obsolescence, or loss of access, may cause regression or stagnation, perpetuating digital disparities. By examining these events, the framework captures the dynamic interplay of external influences and internal responses, providing a lens to understand how transitions between states are shaped and how inequalities can be mitigated or exacerbated over time.

Table 7: Assessment of van Dijk's RAT Using Weber's (2012) Framework.

The adaptation of RAT involved multiple layers of reinterpretation to reflect the organisational level as the unit of analysis accurately. To streamline this process, two types of constructs were identified: primary constructs and contextual constructs. Contextual constructs, which influence digital disparities, are presented in Table 8. This table illustrates the adaptation of internal and external contextual variables, mediators, and macro-level forces to suit an organisational setting. These factors include firm heterogeneities (e.g., size, age, management style, digital endowments, and organisational culture), contextual strategic positioning (e.g., sector, market orientation, supply chain position, and regional location), and resource inequalities (e.g., temporal, financial, and human capital).

The table also provides the rationale for each adaptation, clarifying how these constructs have been tailored to reflect the specific dynamics of firms. All constructs were critically examined to ensure they were well-defined and distinct. For example, motivation was reinterpreted as external incentives created by institutions and technological developments, which encourage firms to adopt digital technologies.

Contextual Constructs	**Original Concept (van Dijk, 2005; 2020)**	**Adaptation for Organisational Context**	**Rationale for Adaptation**
Internal Contextual Variables	*Personal Categories*: These are individual-level attributes such as age, gender, ethnicity, intelligence, personality, and health. They influence a person's inherent ability and motivation to access, develop skills for, and use digital technologies.	*Firm Heterogeneities*: Internal characteristics such as size, age, management style, technological endowments, and organisational culture that shape a firm's digital capabilities.	Firm-level factors introduce heterogeneity in digital readiness and absorptive capacity (Cohen & Levinthal, 1990), influencing adoption patterns (Nelson & Winter, 1985). These characteristics mirror the role of personal traits in individual-level theories.
External Contextual Variables	*Positional Categories*: These refer to the societal and relational roles individuals occupy such as education level, labour market position, household status, social networks, and geographic placement. These affect access to resources and opportunities for digital engagement.	*Contextual Strategic Positioning*: Sector, market orientation (local/global), supply chain position, and location influence firms' access to markets, partners, and institutional resources.	External market conditions align with the TOE framework's environmental dimension (Tornatzky et al., 1990) and with industry-specific innovation systems (Malerba, 2005), shaping strategic opportunities and constraints.

Mediators	*Resources*: These include temporal (time), material (income), mental (technical ability and motivation), social (networks), and cultural (norms) resources. They mediate how personal and positional categories translate into actual digital outcomes.	*Economic Resources*: Temporal, financial, and human capital that determine a firm's ability to invest in technology access, develop skills, and ensure effective usage.	As in IS literature and RBV(Barney, 1991; Orlikowski, 1992), firm resources mediate the link between internal traits and strategic context, affecting digital integration capacity.
Macro-Level Forces	*Technological Properties of ICT*: Hardware, software, and digital content shape usability, affordability, and accessibility. These external technological features can lower or raise barriers to access, skills, and usage.	*External Factors*: Institutional frameworks (e.g., policy support), waves of technological change (e.g., AI, IoT), and market structures (e.g., platform monopolies) all influence the trajectories of digital integration.	Organisational digital transformation is shaped by institutional and market dynamics (Lundvall, 1992; Perez, 2003), going beyond usability to include regulation, innovation cycles, and dominant platform power (Shapiro & Varian, 1998).

Table 8: Adaptation of Contextual Constructs of the Organisational Digital Divide.

Table 9 presents the primary constructs of Access, Skills, and Usage from van Dijk's original theory, which represent the stages of individual engagement with digital technologies beginning with access to technology, progressing to skill acquisition, and culminating in effective utilisation. In the adapted framework for organisations, these constructs are redefined to reflect the stages of digital integration at the firm level. They illustrate how firms acquire digital technologies, develop necessary skills, and integrate these tools into their operations. This offers a comprehensive view of a firm's digital capacity and engagement within the digital economy.

Construct	Original Definition – van Dijk's RAT	Adaptation for Organisational Context	Rationale for Adaptation
Access	Availability of hardware, internet connectivity, and other digital tools to individuals for personal use.	Access refers to the availability and adequacy of foundational digital infrastructure within firms, including hardware, software, and internet connectivity for business operations.	In the firm context, access involves more than physical availability; it includes infrastructure readiness, system integration, and alignment with organisational workflows. This reflects both technology assimilation models in IS (Zhu et al., 2006) and recent digitalisation diagnostics in firms (Cirera et al., 2022).

Skills	An individual's ability to search, evaluate, and use digital information effectively.	At the firm level, digital skills encompass employees' who have a combination of advanced technical skills, analytical abilities, and communication competencies (Hammerbacher, 2009)	The organisational view of skills aligns with the concept of absorptive capacity(Cohen & Levinthal, 1990), where firm-level learning and knowledge integration depend on employee competencies. These skills are critical for translating infrastructure access into meaningful digital use (Shakina et al., 2021).
Usage	Frequency, diversity, and quality of digital tool use by individuals.	Usage refers to the integration of digital technologies across core business functions, from marketing and operations to management systems, conceptualised as layers in a digital technology stack.	In firms, usage reflects a staged integration of digital technologies across core functions, beginning with foundational systems (e.g., ERP, cloud) and evolving toward advanced applications (e.g., AI, analytics). This progression aligns with digital maturity models (Souza et al., 2017) and the concept of a layered technology stack in digital transformation (Siebel, 2019).

Table 9: Adaptation of Primary Constructs

3.4. Theoretical adaptation

3.4.1. Introduction and Overview

Digital disparities among firms have increasingly become a critical factor in shaping economic competitiveness and technological advancement. The ability of firms to effectively integrate digital technologies determines their capacity to innovate (Ciarli et al., 2021), compete (Jerome et al., 2024), and sustain growth in the digital economy. These disparities are not simply the result of unequal access to technology or limited skills but stem from a complex interplay of organisational characteristics, contextual pressures, and macro-level forces.

The adapted RTIF provides a comprehensive basis to explain both the emergence and persistence of digital disparities at the firm level. Building on punctuated equilibrium theory, the framework highlights how technological disruptions, such as artificial intelligence and cloud computing, exacerbate pressures on key resources like financial capital, human capital, and time (Crawford, 2022). These pressures often widen the gap between resource-rich and resource-constrained firms. Institutions attempt to address these disparities through financial incentives, skill development initiatives, and regulatory frameworks (OECD, 2019). However, their responses frequently lag behind rapid technological change, further entrenching inequalities.

Following the evaluation of the RAT, this adaptation extends its scope to organisations as unit of analysis. The adapted framework is presented in four parts: theoretical grounding, contextual and primary constructs, mechanisms and interactions, and broader implications.

3.4.2. Theoretical Grounding

The adapted framework is anchored in four foundational theories that collectively address the complexities of digital disparities among firms. The first is punctuated equilibrium theory, which originates from evolutionary biology and posits that periods of stability are interrupted by bursts of radical change (Gould & Eldredge, 1977). In the context of technological innovation, this theory explains how firms face cycles of incremental improvements interspersed with disruptive transformations, such as the advent of artificial intelligence, cloud computing, and IoT, as well as external shocks like the COVID-19 pandemic (Cattani et al., 2021; Siebel, 2019). These disruptions create significant pressures on firms, exposing gaps in digital readiness. Agile firms often leverage these disruptions for competitive advantage, while lagging firms face heightened risks of obsolescence and survival (Cefis & Marsili, 2005).

Historical and empirical evidence support the application of punctuated equilibrium theory to technological innovation. Mokyr (1990) highlights long periods of economic stagnation disrupted by bursts of innovation, while simulation models by Loch and Huberman (1999) illustrate how technological diffusion often follows these patterns. These findings reinforce the idea that disruptive events shape the evolution of firms and their digital capabilities (Siebel, 2019).

While punctuated equilibrium theory explains the temporal dynamics of technological disruption, how long periods of stability are followed by abrupt change, Schumpeter's theory of creative destruction provides a structural-economic lens through which to interpret the outcomes of such disruptions. According to Schumpeter (1942), innovation is both a transformative and destructive force, enabling dominant firms to consolidate advantages while displacing less adaptable ones. In the digital era, these dynamics are evident: disruptions like cloud computing or AI not only reconfigure production processes but also reshape market structures and competition dynamics. Large, resource-rich firms often act as both initiators and beneficiaries of these shifts, reinforcing platform monopolies, data asymmetries, and technological dependencies. Meanwhile, SMEs and lagging firms face rising costs, technological lock-in, and exclusion from fast-evolving digital ecosystems. Thus, integrating PET with Schumpeter's insights enables a more comprehensive explanation of why disruptive moments exacerbate digital disparities, not merely because of the shock itself, but because of the underlying competitive dynamics and market concentration that shape how firms respond to them.

Building on this, institutional theory highlights the role of formal and informal institutions in shaping firms' incentives and capacities to adopt new technologies. Institutions act as the "rules of the game," creating structural contexts that either foster or constrain digital transformation (Nicoletti et al., 2020; North, 1990). During stable periods, institutions promote incremental technological adoption by supporting infrastructure development, skill enhancement, and market incentives (OECD, 2019). However, during disruptive periods, institutional responses often become reactive, accelerating or constraining the adoption of transformative technologies through financial incentives, regulatory frameworks, or risk mitigation strategies (Schildt, 2022). These institutional pressures exert coercive, mimetic, and normative influences (Bennich, 2023), shaping firms' strategies and perpetuating or alleviating digital disparities.

Finally, van Dijk's RAT provides the reference theory for this adaptation. While initially conceptualised to address societal-level digital inequalities, RAT is reinterpreted here to analyse disparities as an economic phenomenon within organisational contexts. By reinterpreting contextual constructs (e.g., firm heterogeneities, external pressures) and primary constructs (e.g., access, skills, usage), the adapted framework bridges macro-level disruptions, institutional influences, and market structures with firm-level dynamics, offering a comprehensive lens to understand digital divides among firms.

3.4.3. Contextual Constructs

Digital disparities among firms arise from a complex interplay of contextual constructs, which can be classified into four categories: firm heterogeneities, contextual strategic positioning, resources as mediators, and macro-level forces. As shown in Figure 2, firm heterogeneities and contextual strategic positioning influence the availability of resources (e.g., financial, temporal, human capital), which, in turn, determine the progression through the primary constructs of access, skills, and usage. The framework also captures the moderating role of institutions and the disruptive impact of technological innovations on these interactions.

3.4.3.1. Firm Heterogeneities

Firm heterogeneities as we see in Figure 22 refer to intrinsic characteristics, such as size, age, organisational structure, management practices, and technological endowments. Following Rückert et al. (2020), internal attributes significantly influence a firm's capacity to access and utilise resources for digital adoption. Larger firms often benefit from economies of scale, resource availability, and robust infrastructures that facilitate investments in technology and skills development. In contrast, smaller firms may demonstrate greater agility and adaptability, enabling them to implement innovative solutions rapidly, albeit with fewer resources.

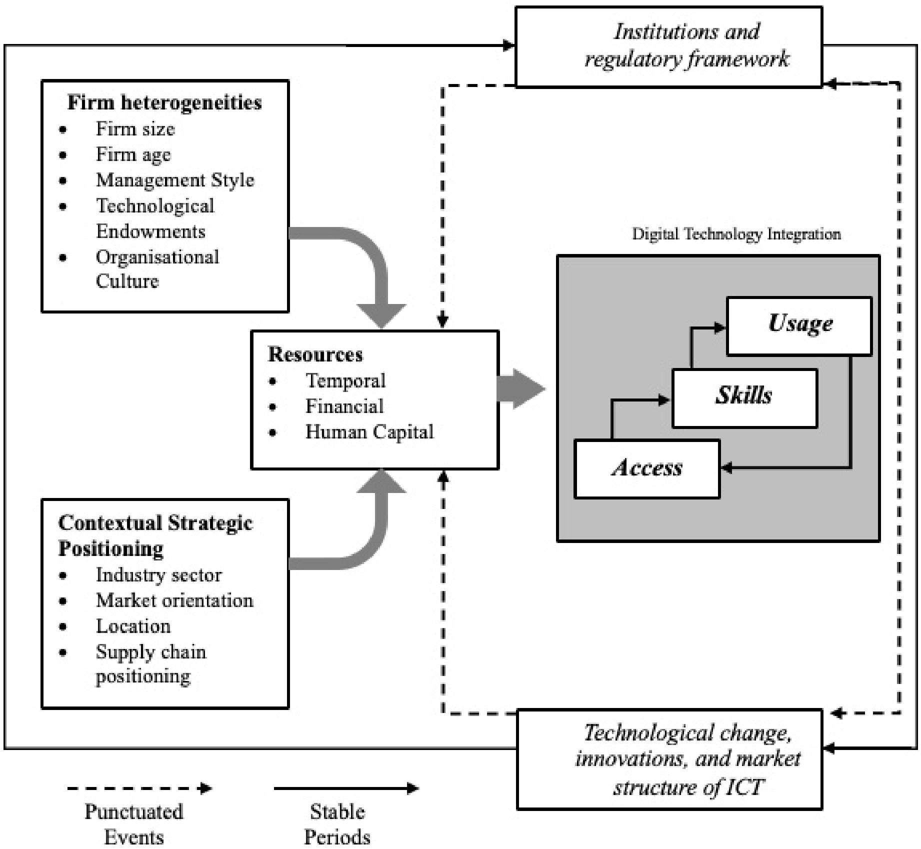

Figure 22: Conceptual Map of RTIF at the Firm Level.
Source: Adapted from van Dijk (2020).

Firm age also plays a pivotal role; younger, 'digital-native' firms are often more technologically inclined and free from legacy systems, which can hinder older organisations (Irani et al., 2023). Additionally, leadership and organisational culture shape digital readiness, with proactive and technologically adaptive management fostering digital integration more effectively than risk-averse approaches.

3.4.3.2. Contextual Strategic Positioning

Contextual strategic positioning refers to external factors that, while shaped by external circumstances, remain within a firm's strategic influence and significantly impact digital integration. As shown in Figure 22 these factors include industry sector, market orientation, geographical location, and supply chain positioning, each of which shapes a firm's digital trajectory differently.

The industry sector dictates technological requirements and opportunities, as the pace and nature of digital adoption vary across sectors with distinct technological needs (Moncada et al., 2024; Rückert et al., 2020). Firms operating in technology-intensive sectors often face greater pressure to adopt advanced solutions compared to those in traditional industries (See Section 4.5). Market orientation, whether local or international, also plays a pivotal role. Firms targeting international markets face heightened competition and typically adopt cutting-edge technologies to remain competitive, whereas firms focused on local markets tend to utilise simpler tools tailored to regional needs (Cassetta et al., 2020).

Geographical location influences technology adoption by determining access to critical infrastructure, talent pools, and regional policy incentives. Urban and economically developed regions often provide significant advantages in terms of connectivity, resources, and institutional support, giving firms in these areas a competitive edge over those in rural or underdeveloped regions (Billon et al., 2017; Thonipara et al., 2023). Additionally, supply chain positioning shapes technological needs and adoption pressures. Firms integrated into global or complex supply chains often require advanced tools to ensure efficiency, integration, and compliance with partner or industry standards (Yang et al., 2021).

3.4.3.3. Resources as Mediators

Resources play a pivotal role as mediators, shaping the effectiveness of firms' digital adoption efforts. They encompass three critical dimensions: financial, temporal, and human capital as illustrated in Figure 22. Financial resources are fundamental for investments in digital infrastructure, training, and advanced technologies, acting as an enabler of firms' capacity to embrace digital transformation. Caldeira and Ward (2003) emphasise that the availability of financial and human resources is crucial for adopting digital technologies, aligning with the resource-based view (RBV) framework. Temporal resources, often overlooked, refer to the time allocated for planning and implementing digital transformation initiatives, a necessity for sustained and meaningful integration of technologies (Kallmuenzer et al., 2024; Valentowitsch et al., 2024).

Human capital, which includes both workforce and managerial digital skills, is equally critical. Valentowitsch et al. (2024) argue that technical competencies, combined with managerial expertise in resource planning, are indispensable for leveraging digital technologies effectively. Disparities in resource availability often create feedback loops, where resource-rich firms achieve greater integration success, thereby compounding their competitive advantages. Conversely, resource-constrained firms struggle to bridge digital gaps, perpetuating disparities and limiting their ability to compete in increasingly digitalised markets.

3.4.3.4. Macro-Level Forces

Macro-level forces, including technological change, institutional frameworks, and market structures, shape the broader landscape of digital technology adoption, as illustrated in Figure 22. Technological change, often described as "incomplete by design" (Garud et al., 2008), underscores the iterative evolution of digital technologies. Rather than stabilising after initial disruptions, digital tools continue to advance, creating recurring punctuated moments that require firms to reassess and adapt their strategies. This dynamic aligns with the punctuated equilibrium framework, where each technological advancement, such as new software versions or breakthroughs in frontier technologies, triggers cycles of organisational and institutional adaptation.

Institutions further influence this process by shaping incentives and constraints through regulatory frameworks, economic policies, and societal attitudes. For instance, tax incentives for technology investments, subsidies for skill development, and standardised digital practices can reduce barriers and promote inclusivity, particularly for smaller firms (Bratta et al., 2020). Conversely, inconsistent regulations or restrictive policies can hinder adoption and exacerbate disparities, especially in sectors or regions with weaker institutional support. As Conyon et al. (2022) emphasise, proactive institutional policies are crucial in countering the market power of digital monopolies and oligopolies, thereby ensuring fair competition and equitable technology diffusion.

Market structures also play a crucial role, particularly on the supply side of digital technologies, where oligopolistic and monopolistic dynamics influence access, affordability, and innovation (Øverby & Audestad, 2021). Dominant players, such as those in the internet, cloud computing, and software industries, often leverage network effects and lock-in mechanisms, consolidating their market power and restricting competition (Birkinshaw, 2023; Conyon et al., 2022). These dynamics can create barriers for smaller firms, which lack the resources to negotiate favourable terms or invest in proprietary solutions. Monopolistic control over standards or pricing can further exacerbate inequalities in access and usage, necessitating institutional interventions to mitigate these effects. From a Schumpeterian perspective, these developments illustrate how innovation, while often associated with progress, can reinforce existing inequalities when captured by dominant firms. Schumpeter's theory of creative destruction highlights that capitalist innovation does not inherently democratise access. Instead, it transforms market structures in ways that benefit incumbents, concentrating capabilities and increasing the vulnerability of digitally lagging firms. Thus, the supply-side consolidation of digital infrastructure reflects not only market failure but also a structural dynamic of innovation, where the benefits of technological progress are asymmetrically distributed.

Together, these macro-level forces interact in complex ways. Technological change reshapes market structures, often reinforcing monopolistic tendencies, while institutions regulate these markets to foster inclusivity and innovation. As noted by Torfs et al. (2023), punctuated events such as policy reforms, technological breakthroughs, or shifts in market dynamics serve as catalysts, compelling firms to reassess their strategies. The dual role of institutions underscores their capacity to either amplify transformational change through proactive policies or entrench disparities through regulatory inertia. This interplay echoes Schumpeter's view of capitalism as an evolutionary process, driven by cycles of innovation that create both opportunity and exclusion. These dynamics emphasise the need for a balanced and forward-looking coordination between institutions, technological change, and market structures to ensure that advancements in digital technologies translate into equitable integration across firms and regions.

3.4.4. Primary Constructs

The primary constructs of this framework—access, skills, and usage—form the foundational dimensions of digital technology integration within firms. Positioned at the core of Figure 22, these constructs encapsulate the key processes involved in adopting and leveraging digital technologies, serving as a framework for analysing disparities in digital readiness and implementation across firms.

3.4.4.1. Access

Access refers to the availability and readiness of digital infrastructure and technologies essential for firms to participate in the digital economy. This construct encompasses both physical dimensions, such as hardware, software, and internet connectivity, as well as logistical elements like cost, reliability, and scalability (Arendt, 2008; Forman, 2005). It serves as the foundational necessary entry point for digital technology integration; without adequate access, firms are effectively excluded from engaging in digital transformation processes. Foundational access includes acquiring basic connectivity and computing tools (Robinson et al., 2020), while advanced access involves high-speed connectivity, cloud computing, and other sophisticated technologies (Ruiz-Rodríguez et al., 2018).

Market structures play a critical role in shaping access. In **concentrated markets** dominated by oligopolistic or monopolistic suppliers, firms often face barriers such as high costs, proprietary standards, and restrictive contracts (Loertscher & Marx, 2020). For instance, dominant cloud providers can impose pricing and technical requirements that are prohibitive for smaller firms, particularly in less competitive or rural markets (Øverby & Audestad, 2021). These dynamics exacerbate inequalities, leaving SMEs and firms in underserved regions with limited options.

Geographic disparities exacerbate these challenges, as rural regions frequently face unreliable infrastructure and limited service coverage (Chipeva et al., 2018). However, concentrated markets can also facilitate standardisation and interoperability, enabling smoother adoption for firms with sufficient resources. Addressing these disparities requires institutional interventions, such as subsidies, competitive pricing regulations, and rural infrastructure investments, to ensure equitable access (Bratta et al., 2020).

3.4.4.2. Skills

Skills represent the human capital required to utilise and integrate digital technologies within firms effectively. This construct spans a spectrum from basic digital literacy among employees to advanced expertise in domains like data science, AI, and IoT (Aydın, 2021; Shakina et al., 2021). At the operational level, skills include competencies in using foundational technologies such as ERP systems, CRM platforms, and digital communication tools (Cirera et al., 2022).

The framework differentiates between general digital skills, which are broadly applicable across firms, and specialised skills, tailored to specific industries or advanced technologies. Disparities in skills often arise from mismatches between the supply and demand of digitally skilled workers, as well as unequal access to training opportunities (Gekara et al., 2019). These inequalities are exacerbated by differences in firm size and resources, with larger or resource-rich firms better equipped to invest in upskilling their workforce, leaving smaller firms at a disadvantage in building digital readiness.

The market structure shapes the demand for highly specialised skills tied to proprietary platforms or ecosystems, such as certifications for dominant cloud services or enterprise software (Conyon et al., 2022). These market dynamics create significant barriers for smaller firms, which frequently lack the resources to invest in costly training programs or certifications required to compete in concentrated markets. Moreover, proprietary systems and vendor lock-in mechanisms exacerbate skill dependencies, compelling employees to acquire platform-specific expertise to effectively utilise these technologies (Gawer, 2014; Øverby & Audestad, 2021). This reinforces inequalities, as firms with limited budgets and access to training opportunities face greater challenges in bridging the skills gap in an increasingly specialised digital landscape.

In contrast, market standardisation in some foundational technologies, such as office software or digital communication tools, has reduced the learning curve for general skills, enabling broader adoption across firms. However, this benefit is often insufficient for addressing the growing demand for advanced, industry-specific expertise. Unequal access to certifications and advanced training further deepens the skills divide, particularly in less competitive regions or sectors with limited institutional support (Chipeva et al., 2018).

3.4.4.3. Usage

Usage refers to the extent and sophistication with which digital technologies are integrated into a firm's operations, strategies, and value-creation processes. This construct captures both basic adoption and advanced deployment of digital tools. To systematically analyse these disparities, this framework introduces the concept of the digital technology stack, adapted from Siebel's (Siebel, 2019) model of layered technological adoption, as shown in Figure 23.

The digital technology stack serves as an analytical tool to assess stratified digital integration within firms, where each layer represents a different level of technological capability and engagement. Figure 23 visually distinguishes these layers, with foundational technologies depicted in light grey and advanced technologies in dark grey.

At the foundational level, the stack includes essential systems such as ERP, CRM, and other data management tools, alongside customer-facing platforms like websites, social media, and e-commerce (Cirera et al., 2022). These technologies are critical for establishing a digital presence and supporting basic operational efficiency. The advanced level, by contrast, comprises cutting-edge technologies such as cloud computing, IoT, data analytics, and AI. These tools enable predictive analytics, scalability, and data-driven decision-making, providing firms with significant competitive advantages.

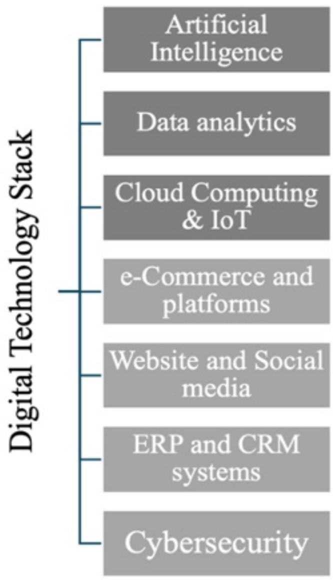

Figure 23: Digital Technology Stack.
Source: Adapted from Siebel (2019).

However, disparities in the capacity to integrate technologies across the stack are pronounced. Firms integrating technologies from the higher layers are typically resource-rich and better equipped to manage the skills, infrastructure, and organisational changes required for advanced tools (Calza et al., 2021; Zolas et al., 2020). Smaller firms or those in underserved regions face barriers such as high costs, complex implementation, and limited interoperability, restricting them to lower layers of the stack. Moreover, skills availability plays a pivotal role in determining a firm's ability to advance through the stack, as the adoption of AI and IoT often requires specialised expertise (Spiezia, 2016).

By offering a structured lens to examine the usage divide, the digital technology stack highlights where firms stand in their digital integration journey. Firms leveraging advanced layers of the digital technology stack gain a significant edge in adapting to market dynamics, fostering innovation, and achieving long-term growth. Conversely, firms reliant on foundational technologies encounter limitations that hinder progress and deepen disparities in digital integration. Addressing these gaps requires targeted interventions, including subsidies, training programs, and public-private collaborations, to ensure that firms of all sizes can fully leverage the benefits of digital transformation.

3.4.5. Sectoral Digital Divide

Using the RTIF, sectoral disparities in digitalisation can be analysed through the interplay of access, skills, and usage, influenced by financial resources, human capital, and time. High-tech sectors, such as finance, ICT, and telecommunications, benefit from superior access to cutting-edge digital infrastructure and advanced tools like AI, IoT, and cloud computing. These sectors also possess the necessary skills and expertise to integrate these technologies effectively, enabling them to harness digital innovations at a faster pace and with greater sophistication (Siebel, 2019). In contrast, other sectors, such as agriculture or traditional manufacturing, often face restricted access to digital infrastructure, limited skills for advanced applications, and constrained usage due to lower resource availability (Cirera et al., 2022).

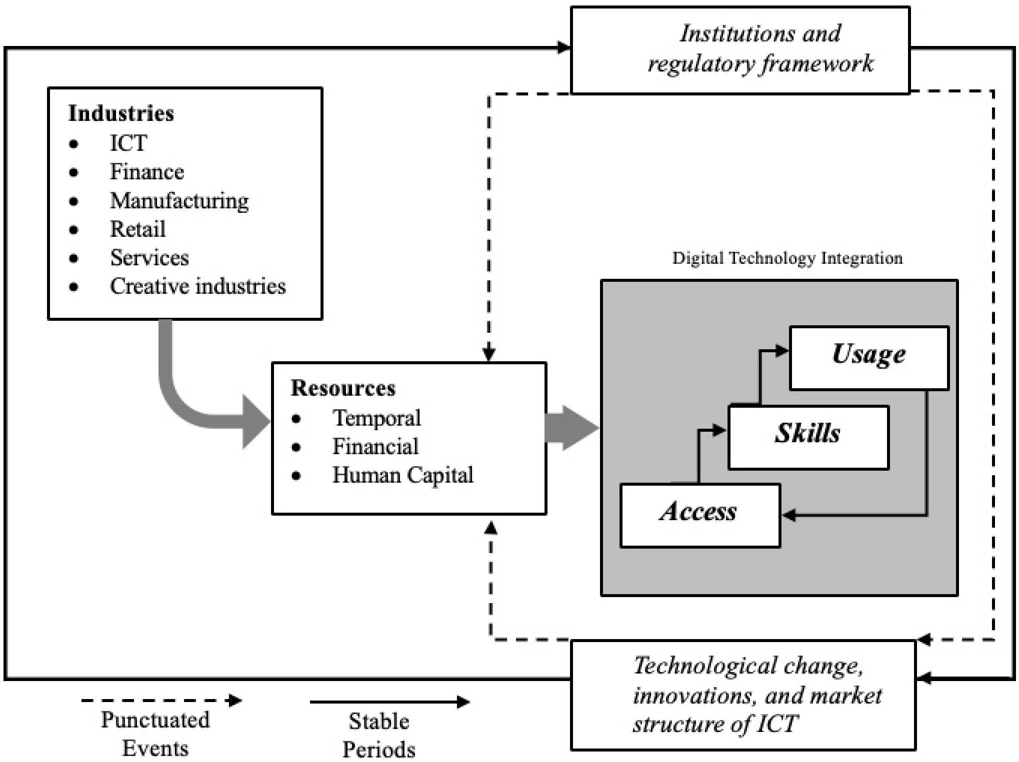

Figure 24: Conceptual Map of RTIF at the Sectoral Level.

Source: Adapted from van Dijk (2020).

The conceptual map in Figure 24 highlights how disparities in digitalisation are not merely a function of the three primary constructs but also result from broader contextual dynamics, including market structures, institutional support, and resource availability. Market structures significantly shape sectoral digital adoption. For instance, sectors relying on monopolistic or oligopolistic suppliers for critical technologies often face higher costs and limited customisation options, creating barriers to advanced adoption (Conyon et al., 2022; Øverby & Audestad, 2021). Conversely, open-source platforms and standardised foundational tools have lowered entry barriers for less resource-intensive sectors, enabling wider adoption of general-purpose technologies.

From a Schumpeterian perspective, these sectoral disparities reflect a structural pattern inherent to capitalist innovation: the cyclical reorganisation of industries where innovation benefits those already equipped with the means to adapt. High-tech sectors act as "creative agents," able to internalise technological advancements and restructure themselves around new paradigms, while less-digitally intensive sectors often absorb innovation slowly or are disrupted without deriving a competitive advantage. As Schumpeter noted, technological change reshapes entire industries, but its effects are uneven; those unable to capitalise on new technologies are gradually displaced or marginalised. This dynamic helps explain why certain sectors, despite policy efforts or digital readiness frameworks, remain persistently behind in digital transformation trajectories.

Resource availability, such as financial capital, human capital, and time also determines a sector's capacity to progress through the digital technology stack. High-tech sectors often attract more public and private investment, facilitating the faster adoption of advanced tools and greater opportunities for workforce upskilling. In contrast, resource-constrained sectors, such as agriculture or small-scale manufacturing, frequently struggle to climb beyond the foundational layers of the stack, perpetuating inequalities in digital integration (Calza et al., 2021).

Punctuated events and industrial policy interventions play pivotal roles in shaping the digital trajectories of sectors. Breakthroughs in generative AI represent a recent, punctuated event, transforming knowledge-intensive and service-based industries by automating cognitive tasks, generating content, and analysing data. Similar to prior shifts, such as IoT-driven automation in logistics and manufacturing, this development accelerates innovation in AI-integrated sectors, enhancing efficiency and decision-making processes (Siebel, 2019). However, such events risk widening the digital divide, as sectors with lower digital capabilities may struggle to adapt, particularly if they lack financial resources, institutional support, or a workforce trained in AI-driven processes.

Industrial policies, including targeted AI adoption programs, digital literacy initiatives, and adaptive regulatory frameworks, can mitigate these disparities by fostering inclusive access to emerging technologies (Bratta et al., 2020; Gruber, 2019). Public-private collaborations play a key role in ensuring that sectors with lower digital intensity are not excluded from the benefits of technological advancement. Without such interventions, the uneven diffusion of generative AI could further entrench sectoral inequalities, favouring industries with greater absorptive capacity while leaving others behind in the digital transformation process.

The digital technology stack provides a structured lens to examine sectoral divides. High-tech sectors often integrate advanced layers of the stack, leveraging tools like AI, data analytics, and cloud computing for predictive decision-making and scalability. In contrast, lower-intensity sectors remain reliant on foundational tools, such as CRM systems or basic e-commerce platforms, limiting their strategic capabilities and competitiveness. This layered framework highlights the importance of sector-specific strategies in addressing disparities, particularly for sectors constrained by proprietary systems or oligopolistic markets (Conyon et al., 2022).

Through the RTIF, it becomes evident that addressing sectoral disparities requires a systemic approach. This includes aligning industrial policies with the specific needs of different sectors, fostering resource availability, and preparing for the disruptive effects of punctuated events. Moreover, ensuring equitable access to training and reducing dependencies on monopolistic suppliers can help less advanced sectors progress through the stack, enabling them to fully participate in the digital economy.

3.4.6. Regional Digital Divide

Regional disparities in digitalisation can be effectively analysed through the Resources and Technology Integration Framework (RTIF), which conceptualises the digital divide through the sequential and interdependent constructs of access, skills, and usage, shaped by institutional, economic, and geographic factors. As illustrated in Figure 25, the framework recognises regional context, specifically urban–rural divides, as a key determinant influencing firms' access to temporal, financial, and human capital, which in turn conditions their capacity to integrate digital technologies. Access to broadband and computing infrastructure varies substantially across regions. Urban areas tend to benefit from higher-quality connectivity, faster network deployment, and the presence of innovation ecosystems, while higher service costs, limited infrastructure, and lower investment returns often characterise rural areas (Billon et al., 2009; Ruiz-Rodríguez et al., 2018). These access constraints pose an initial barrier to digital adoption, particularly in less developed regions, and influence the downstream development of digital skills and effective technology usage.

Disparities in regional skill development and usage patterns are closely interlinked. Urban centres, due to their proximity to universities, technical training institutes, and industrial clusters, tend to generate and retain a digitally skilled workforce (Caravella et al., 2023; Moncada et al., 2024). This skilled labour pool enhances local firms' absorptive capacity and facilitates the uptake of advanced digital tools. Conversely, rural and peripheral areas often suffer from persistent skill shortages and "brain drain" as talent migrates to more dynamic urban centres (Labrianidis & Kalogeressis, 2006; Miguelez & Moreno, 2015). These structural disadvantages limit local firms' ability to sustain meaningful digital integration, even when access to infrastructure is eventually improved.

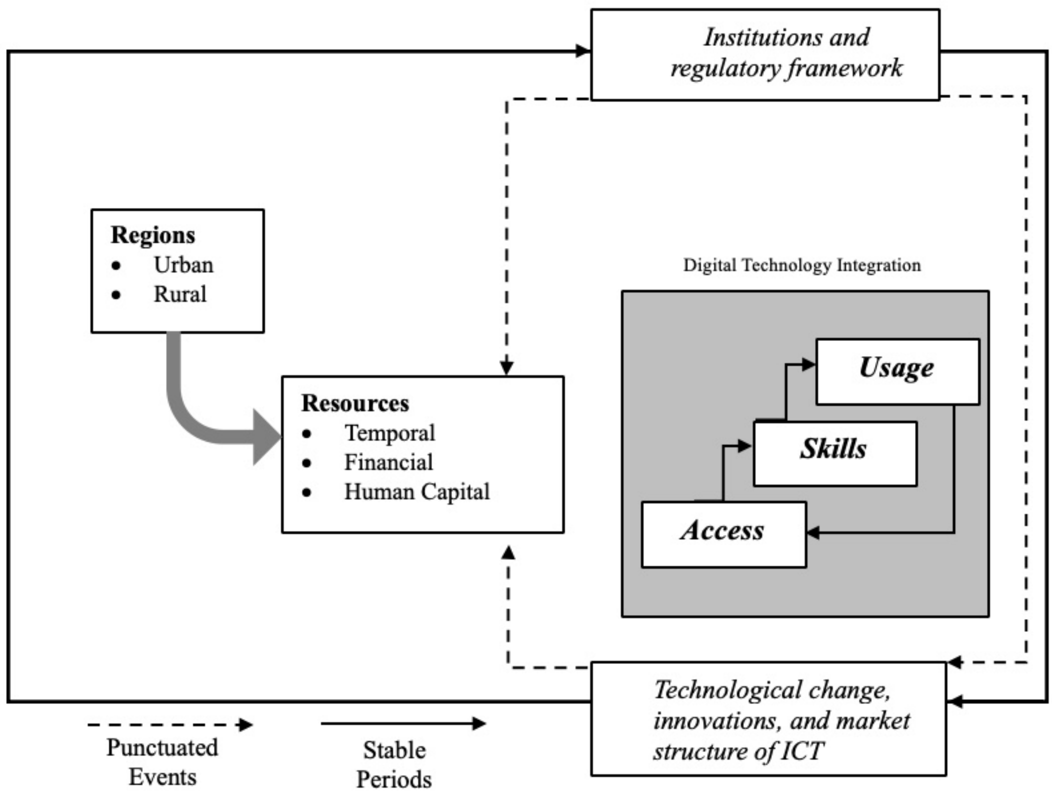

Figure 25: Conceptual Map of RTIF at the Regional Level.
Source: Adapted from van Dijk (2020).

The market structure of digital technologies further shapes the regional digital divide. Oligopolistic control of critical technologies, such as broadband infrastructure and cloud platforms, often favours resource-rich urban regions, where providers prioritise investment due to higher returns. This leaves rural areas and smaller markets underserved, widening access disparities (Nicoletti et al., 2020). Similarly, proprietary ecosystems for enterprise tools and certifications disproportionately benefit regions with advanced industries and skilled labour, while excluding regions unable to meet the high costs or training demands required to participate in these ecosystems (Øverby & Audestad, 2021).

Finally, regional digital divides are not static; they evolve in response to external disruptions and the institutional capacity to absorb change. For instance, **punctuated events** like the COVID-19 pandemic have highlighted significant asymmetries in regional responses to technological disruptions. As shown by Dyba and Di Maria (2023), regions with pre-existing digital infrastructure and coordinated institutional support accelerated their digital transformation, while others without such foundations lagged further behind. These findings reinforce the RTIF's emphasis on the role of **institutional frameworks and adaptive capacity** in mediating regional digital trajectories (Nicoletti et al., 2020), ultimately determining whether digitalisation acts as a force for convergence or divergence.

3.4.7. Assumptions

The revised assumptions presented in Table 10 reflect the complexities and realities of analysing the digital divide at the firm level. Unlike frameworks designed for societal or individual-level analyses, the RTIF adapts to the unique dynamics of firms as the unit of analysis. These assumptions account for the iterative nature of digital technology adoption, the stratified progression through the digital technology stack, and the influence of external forces such as institutions, market structures, punctuated technological events, and creative destruction processes.

Assumption	Description	Implications
Sequential Interactions of Constructs	Access, skills, and usage interact sequentially, reflecting path-dependent processes of capability building (Nelson & Winter, 1985; Venkatesh et al., 2003).	The feedback loop from usage to access (Rosenberg, 1972) highlights the iterative nature of digital integration, enabling firms to refine foundational elements as they progress.
Resource Dependency	Temporal, economic, and human resources act as enablers or constraints, consistent with the resource-based view and absorptive	Resource-rich firms progress effectively through the digital technology stack, while resource-constrained firms risk

	capacity theory (Barney, 1991; Cohen & Levinthal, 1990).	stagnation or regression (Tornatzky et al., 1990).
Layered Progression	Companies advance through digital transformation in stages, progressing from basic connectivity to advanced technologies, as shown in digital maturity models (Thordsen & Bick, 2023) and technology adoption studies (Zhu et al., 2006). Sector-specific and institutional factors significantly influence these pathways, as noted in innovation systems literature.	This layered progression may contribute to widening digital divides, as firms with advanced integration unlock strategic benefits inaccessible to those stuck at foundational levels (Bharadwaj, 2000; Siebel, 2019).
Institutional Moderation	Institutions shape technology uptake by offering incentives or imposing constraints, aligning with (Acemoglu & Robinson, 2013) view of inclusive and extractive institutions.	Supportive institutions mitigate disparities, while inconsistent or restrictive policies exacerbate sectoral and regional inequalities (Nelson, 1993).
Contextual Dependence	Digital integration is shaped by firm heterogeneity and context, including size, age, and geography and industry (Donaldson, 2006; Syverson, 2011).	High-tech sectors and urban areas benefit from stronger ecosystems, while rural and traditional firms face structural barriers (Porter, 1980).
Cyclical Technological Change	Technological progress unfolds in stable and disruptive phases, echoing the dynamics of creative destruction and techno-economic paradigms (Schumpeter, 1942).	Punctuated events (e.g., AI breakthroughs, pandemics) disrupt trajectories, creating opportunities for agile firms but widening divides for less adaptable ones (Levinthal, 1998).
Sectoral and Regional Dynamics	Innovation systems vary by sector and region, with uneven institutional, financial, and knowledge infrastructures (Asheim & Gertler, 2006; Malerba, 2005).	High-tech and urban areas advance faster due to stronger support, while lagging regions require targeted intervention to avoid deepening divides.

Impact of Market Structures	Digital markets are often dominated by platform monopolies and oligopolies, which shape access and pace of adoption (Shapiro & Varian, 1998; Varian, 2014).	Dominant firms control standards and ecosystems, consolidating advantages for well-resourced adopters while increasing dependencies for others (Conyon et al., 2022; Øverby & Audestad, 2021).

Table 10: Assumptions of the adapted framework RTIF

3.4.8. Mechanisms and Interactions

This section explores the mechanisms underlying firms' digital technology integration across two distinct scenarios: **stable periods** and **punctuated events**. Stable periods are characterised by gradual technological advancements and predictable resource allocation, enabling firms to steadily progress in adopting and utilising digital tools. In contrast, punctuated events, such as major innovations or regulatory shifts, introduce sudden disruptions, compelling firms to rapidly reallocate resources and adapt their strategies to new conditions. Stable periods and punctuated events are scenarios that highlight the dynamic interplay between external forces, resource dynamics, and organisational outcomes, illustrating how firms respond to varying pressures in their digital integration trajectories.

3.4.8.1. Feedback Loops in Stable Periods

Stable periods, represented by the solid lines in Figure 22, are characterised by incremental technological change, predictable market dynamics, and consistent institutional frameworks. These periods allow firms to progress steadily in digital technology integration, leveraging available resources to improve access, develop skills, and enhance usage. Firms can systematically catch up or advance through the digital technology stack, depending on their specific goals and existing capabilities. Institutions play a proactive role in supporting this progression by enforcing industrial policies, offering tax incentives, and providing workforce training programs that reduce barriers for resource-constrained firms. During stable periods, the predictable nature of technological and market dynamics can reduce some barriers to technology adoption, creating opportunities for gradual improvement, particularly for firms with adequate resources.

The solid lines in the conceptual framework illustrate the reinforcing feedback loops that emerge during these periods. As firms improve access to digital infrastructure, they build the skills needed to use these technologies effectively. Enhanced usage generates organisational benefits, which incentivise further investment in access and skills, creating a positive cycle of progress. This sequential progression, from access to skills to usage, forms the core of firms' digital integration efforts. Resource-rich firms can navigate this process with ease, while resource-constrained firms may require institutional support to address gaps in resources or capabilities. Market structures, particularly in oligopolistic sectors, also influence this progression. Vendor lock-in conditions and dependencies on dominant technology providers can slow firms' adoption or limit their flexibility, even in stable periods.

These mechanisms highlight the interactions between institutions, regulatory frameworks, technological change, and market structures, as well as the inner relationships among access, skills, and usage. While stable periods provide an environment of lower resource pressure, disparities remain as firms compete for resources and navigate structural barriers. The feedback loops reinforce steady advancements for resource-rich firms while perpetuating gaps for those with limited resources, particularly in less competitive market environments. The transition from usage back to access reflects the iterative nature of digital integration, as benefits from usage can inspire firms to reinvest in foundational infrastructure to support future advancements.

3.4.8.2. Feedback Loops in Punctuated Events

In contrast to stable periods, punctuated events introduce sudden and disruptive shifts in the technological landscape, compelling firms to adapt to new paradigms of digital integration. Represented by the dashed lines in Figure 22, these events arise from breakthrough innovations, regulatory transformations, economic shocks, or geopolitical disruptions that significantly alter market dynamics (Priestley et al., 2020; Sood & Tellis, 2007). Unlike the gradual and predictable progression observed during stable periods, punctuated events force firms to respond to rapid changes in access, skills, and usage under intensified resource constraints.

Institutions adopt a reactive role in these transitions, implementing strategies that either amplify or mitigate the impact of disruptions (Quach et al., 2022). Amplification measures, such as emergency subsidies, accelerated training programmes, or regulatory adjustments, aim to facilitate the swift adoption of disruptive technologies (Bratta et al., 2020). Conversely, mitigation efforts include regulatory interventions designed to manage risks associated with privacy, ethical considerations, or monopolistic market control (Quach et al., 2022). While these responses seek to stabilise the technological transition, they also create acute pressures on firms, particularly regarding the financial and human capital required to integrate new digital tools effectively.

Punctuated events place heightened demand on critical resources such as financial capital, skilled labour, and organisational time for technology deployment. Firms with uneven access to these resources face significant challenges in progressing through the sequential stages of access, skills, and usage. Resource-rich firms can swiftly mobilise investments to secure access to emerging technologies, upskill their workforce, and deploy digital solutions, accelerating their transition through these stages. In contrast, resource-constrained firms often become stuck in early stages, struggling to acquire the necessary infrastructure or personnel to adapt. This uneven distribution of resources exacerbates existing disparities, as resource-rich firms consolidate their competitive advantages while others fall further behind.

The interaction between resource constraints and market structures further amplifies these disparities. Dominant technology providers often dictate the pace of adoption by controlling access to new tools or creating vendor lock-in scenarios and imposing dominance with proprietary ecosystems that limit interoperability. As a result, firms with limited resources or strategic flexibility face significant hurdles in adapting to punctuated events. These dynamics highlight how punctuated events reshape competitive landscapes, reinforcing the divide between digitally advanced and lagging organisations.

3.4.9. Practical Implications

The adapted framework provides significant practical implications for firms and policymakers, offering a comprehensive lens to address the mechanisms driving disparities in digital technology integration.

For firms, the framework highlights the necessity of adopting a holistic and strategic approach to digital adoption by recognising the interdependence of access, skills, and usage. Studies like Cirera et al. (2022), Seclen-Luna et al.(2022), and Bratta et al. (2020) emphasise that isolated investments in digital infrastructure or skills development often fail to yield meaningful outcomes unless accompanied by complementary improvements across all dimensions. For instance, firms investing in advanced technologies like AI and IoT (usage) without ensuring adequate digital skills within their workforce often experience underutilisation of these tools. The framework encourages firms to assess and iteratively strengthen weaknesses in their digital technology stack, enabling them to navigate disruptions and maintain competitive advantages in the evolving digital economy (Siebel, 2019). By leveraging the feedback mechanisms described in this framework, firms can align their investments in technology adoption with workforce development and process integration, thereby enhancing their resilience and adaptability to rapid technological change.

For policymakers, the framework underscores the pivotal role of institutional support in mitigating digital disparities and fostering equitable technological progress. Studies on institutional influence, such as Alfaro-Serrano et al., (2021) and Vu et al., (2024), highlight how targeted interventions can reduce regional and sectoral disparities in digital adoption. The framework suggests that policies promoting access to foundational infrastructure, such as affordable internet and computing technologies, are essential for reducing the access divide. Moreover, initiatives incentivising skill development through subsidised training programmes and workforce upskilling can address the skills and the usage divide, particularly for SMEs that often lack the resources to invest in digital competencies (Caravella et al., 2023).

During periods of technological disruption, targeted interventions such as financial subsidies, accelerated training initiatives, and regulatory adjustments are critical for enabling firms to adapt quickly and avoid falling behind. For example, governments can provide tax incentives for firms adopting advanced technologies or establish partnerships with educational institutions to offer industry-relevant digital training (Chen et al., 2021; Chen et al., 2023). Policymakers should also consider fostering collaborative ecosystems by aligning efforts between private firms, educational institutions, and government bodies. Such collaborations can create long-term solutions for equitable digital integration, enabling firms across regions and sectors to compete on a more level playing field.

3.5. Discussion

The adapted RTIF demonstrates considerable strength as an explanatory framework, offering insights into how digital disparities emerge and persist across firms. By integrating constructs such as access, skills, and usage within a sequential and iterative progression, the RTIF captures the complexity of digital integration processes, addressing gaps left by existing models. Furthermore, its focus on contextual factors, such as institutional influences and market structures, provides a nuanced understanding of the external forces shaping digital adoption.

A key limitation lies in the exclusion of an outcomes dimension, which, in the original model by van Dijk (2005, 2020), accounted for the benefits of technology adoption. While the RTIF prioritises understanding disparities, adding an outcomes layer could bridge the gap between digital adoption and its organisational consequences, such as innovation, competitiveness, and performance. This addition could extend the framework into Gregor's (2006) "Type IV: Theory for Explaining and Predicting," enabling it to generate testable propositions about the organisational and economic impacts of digital transformation.

Additionally, while the RTIF is well-suited for explaining disparities, its predictive capacity in emerging technological contexts, such as artificial intelligence (AI), remains underexplored. Enhancing the framework's ability to anticipate how varying levels of access and skills influence firms' integration of future technologies could significantly benefit policymakers and researchers. This predictive capacity would allow for proactive measures to mitigate digital disparities.

In summary, the RTIF excels as an explanatory model, yet its applicability to predictive analyses and outcomes remains an avenue for future exploration. Addressing these limitations would make the framework more robust and adaptable to evolving technological and market dynamics, thereby furthering its contribution to understanding digital disparities.

3.6. Conclusions

This chapter has proposed an adapted RTIF to explain how disparities in digital technology adoption emerge and persist over time. The framework advances existing theories by conceptualising access, skills, and usage as part of a sequential and iterative model, incorporating both internal organisational factors and external market and institutional forces. By examining the structural and organisational factors driving these disparities, including firm size, sectoral heterogeneities, resource endowments, and institutional support mechanisms, the framework provides a more comprehensive perspective on how firms navigate digital transformation. Furthermore, the role of market structures, particularly those shaped by monopolistic and oligopolistic technology providers, is critically assessed as a mediating force in firms' digital trajectories.

The research questions outlined at the beginning of this chapter have been addressed by identifying the key mechanisms that shape firms' progression through access, skills, and usage. The RTIF highlights how market structures and institutional policies mediate digital adoption, demonstrating that while stable periods provide opportunities for incremental progress, punctuated technological disruptions create resource pressures that can either accelerate or stall digital integration, deepening disparities. This dual perspective enhances the framework's explanatory power by capturing the dynamic and contingent nature of digital technology integration, recognising that disparities are not static but evolve in response to technological and institutional shifts.

The RTIF offers a robust theoretical foundation for analysing firm-level digital disparities. In the next chapter, the framework will be empirically tested using firm-level data from Italy, examining regional, sectoral, and firm size disparities. This application will assess the framework's practical utility in explaining digital inequalities and its ability to identify patterns of digital integration across different organisational and economic contexts.

In conclusion, the RTIF represents a significant advancement in the study of the digital divide by integrating a structural, institutional, and technological perspective into firm-level analyses. It provides a conceptual foundation for future research, including its application to emerging technological divides, such as the adoption of artificial intelligence, and paves the way for actionable insights that can inform policy interventions and strategic digital transformation initiatives aimed at fostering equitable technology integration across firms and sectors.

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Chapter 4 - Exploring Patterns and Shifts: Factor Analysis of the First and Second-Level Digital Divide in Italian Enterprises

Abstract: This study leverages the adapted RTIF to examine digital integration among Italian firms, focusing on the core constructs of access, skills, and usage as core dimensions of organisational digital engagement. Moving beyond individual-level digital divide frameworks, this research adapts these constructs to the organisational context, analysing how firms adopt and utilise digital technologies across economic activities and regions. Using ICT usage survey data from 2014 to 2019, a repeated cross-sectional approach is applied to assess participation in the digital economy among Italian enterprises. Factor Analysis of Mixed Data (FAMD) and Multiple Correspondence Analysis (MCA) are used to develop composite indices for access, skills, and usage, capturing latent variables that shape firms' digital trajectories. The Gini coefficient quantifies inequalities within these indices, offering a robust measure of disparities across firm size, sector, and regional levels. Preliminary findings reveal distinct patterns: larger firms demonstrate greater access to foundational digital resources, including connectivity and computing tools, while smaller firms face barriers due to resource constraints. Sectoral variations highlight how technological requirements influence adoption, with advanced industries achieving higher levels of integration. Regional analysis reveals persistent gaps, as northern regions excel in access, but southern regions lag in skills development, ultimately limiting effective usage. Although institutional interventions have improved access over time, gaps in skills and usage persist, continuing to impede firms' ability to fully leverage digital technologies. This underscores the need for policymakers to strike a balance between investments in expanding access and initiatives focused on skill development and integrating digital tools into core business operations. By addressing these disparities, this research contributes to shaping strategic frameworks for inclusive and sustainable digital transformation across firms of varying sizes, sectors, and regions.

Keywords: Digital divide, factor analysis, Italian firms, digital adoption, Gini index.

JEL Classification: O33, L86, C83, D22, R12, O38, I28.

4.1. Introduction

The rapid advancement and growing adoption of digital technologies have become a double-edged sword in the contemporary digital era. On the one hand, these technologies offer unprecedented opportunities for businesses to reshape their models (Trischler & Li-Ying, 2023), foster innovation (Ciarli et al., 2021), and gain competitive advantages (Jerome et al., 2024). On the other hand, the unequal adoption of these technologies has also led to a significant challenge: the digital divide. The existing literature categorises the digital divide into three distinct levels. The first level addresses disparities in access to computing technologies and internet connectivity (van Dijk, 2020; van Dijk & Hacker, 2003). The second level explores the differences in digital skills and the variations in how actors in society use these technologies (Hargittai, 2002; Scheerder et al., 2017). The third level focuses on the unequal outcomes that arise from the varied uses of digital technologies (Ragnedda, 2017; Van Deursen & Helsper, 2018). This divide manifests itself not just between individuals but also, importantly, within organisations and government administrations, affecting society and the economy in multifaceted ways.

At the firm level, the digital divide is characterised not only by mere access to computer technologies and internet connectivity. It also encompasses disparities in companies' abilities to access digital skills and integrate these technologies into core business operations. Although much research has been conducted on the digital divide, shifting the focus beyond individual analysis allows for a deeper exploration of this phenomenon at the organisational level (Bach et al., 2013; Lythreatis et al., 2022; Shakina et al., 2021).

Bridging these digital disparities is crucial for modern businesses seeking to enhance performance, optimise operations, and gain a competitive advantage (Cusolito et al., 2020; Koch & Windsperger, 2017; Mosiashvili & Pareliussen, 2020; Scuotto et al., 2017). However, it is crucial to approach digital adoption with caution. Usai et al. (2021) and Lambert et al. (2023) warn against accepting digital technologies as universal solutions, highlighting instances where digital adoption has not yielded the anticipated positive outcomes or even led to negative impacts. Analysing this debate through the lens of the digital divide reveals that disparities in access, skills, and use of digital technologies are significant barriers that prevent firms from fully capitalising on the benefits of digitalisation.

Initial research on the digital divide has shown that digital inequalities between individuals often intersect with and exacerbate other socioeconomic disparities, such as income, gender, race, and education (Lengsfeld, 2011; Ragnedda & Muschert, 2013; van Dijk, 2006). This phenomenon, which sees digital divides augmenting preexisting inequalities, could be mirrored within firms. Firms may face not only barriers to adopting digital technologies but also a widening gap due to other internal disparities in areas such as productivity, size, and wage structures, as outlined by Loecker et al. (2022) in their study of the US and UK economies. Given these findings, it is reasonable to consider that a similar scenario could exist in the Italian business landscape.

Thus, the digital divide within Italian firms may not reflect a mere technological gap but the interaction of factors contributing to these disparities, including firm-specific heterogeneities, contextual strategic positioning of firms, unequal access to essential resources, emergence of disruptive digital technologies and regulatory frameworks. The development of digital technologies often follows a trajectory marked by gradual adoption, interspersed with punctuated events, such as the introduction of advanced tools like cloud computing or generative AI, which can abruptly redefine competitive landscapes. These differences underscore the complex nature of the digital divide, which is influenced not only by technological factors but also by interwoven socioeconomic elements, including cultural attitudes towards digital adoption (Goran et al., 2017).

Understanding the digital divide at the organisational level is crucial because it directly impacts a firm's ability to compete, innovate, and grow in the digital economy. Organisations that fail to adopt and integrate digital technologies effectively risk falling behind their peers, which can lead to broader economic inequalities and hamper overall economic growth. Analysing the digital divide within firms helps identify specific barriers and challenges that different types of organisations face, providing insights for targeted interventions and policies that can promote digital inclusivity and economic resilience.

Italy presents an interesting case for studying the digital divide among firms due to its unique economic structure, characterised by a high prevalence of small and medium-sized enterprises (SMEs). SMEs are crucial to the Italian economy, making up 80% of employment and 70% of added value (EIB, 2021). Despite their importance, SMEs often face significant challenges in digital technology adoption compared to larger firms, exacerbating the digital divide. Therefore, the implications of the digital divide are particularly pronounced, depending on the size of the firm, the economic sector, and the region. For instance, according to the EIB, sectors like finance and tourism exhibit higher but modest levels of digital adoption compared to Germany and France, while manufacturing and retail lag behind. Additionally, the Italian economy exhibits significant regional disparities and sectoral heterogeneity, further complicating the landscape of digital integration (Cirillo et al., 2021). This scenario is consistent with the high degree of firm heterogeneity that characterises the structure of the Italian economy at both geographical and sectoral levels (Bugamelli et al., 2020) and with the 'neo-dualism' that has been identified between a few high-performing firms and a large group of low-performing laggard firms (Dosi et al., 2018).

The digital divide intensifies preexisting disparities in productivity and wage structures, limiting growth opportunities for smaller firms and widening the gap between those who can harness digital technologies and those who cannot. This complex web of challenges highlights the importance of addressing the digital divide as a central factor influencing the broader economic dynamics and firm-level disparities in Italy.

The RTIF offers a structured lens to analyse digital disparities among firms. It conceptualises digital integration as a sequential process starting with access to technology, followed by the development of digital skills, and culminating in the effective usage of digital tools across business operations. While this progression is generally linear, the framework acknowledges that more advanced usage may occasionally lead firms to reassess and expand their digital infrastructure. This perspective helps explain why disparities emerge and persist across different sectors, regions, and firm sizes, particularly when structural constraints limit a firm's ability to fully engage with digital transformation. Moreover, digital disparities within this framework are shaped by contextual factors, including firm heterogeneities, resource availability, and external influences such as regulatory changes and technological disruptions.

The RTIF provides the foundation for examining digital disparities among Italian firms in this study, focusing on how core constructs such as access, skills, and usage shape firms' digital integration across different sizes, sectors, and regions. Factor Analysis of Mixed Data (FAMD) and Multiple Correspondence Analysis (MCA) are employed to develop composite indices for these constructs, capturing latent dimensions of digital integration. To measure inequalities within these indices, the Gini coefficient is applied, offering a robust method to evaluate disparities in digital adoption and integration over time.

Digital transformation is often viewed as a linear process, where improvements in access to digital technologies naturally lead to more sophisticated skills and, ultimately, widespread usage. However, this assumption overlooks the role of structural constraints, such as firm size, sectoral characteristics, and regional disparities, that influence the way businesses adopt and integrate digital tools. While larger firms may possess the resources to leverage digital technologies effectively, smaller firms often struggle with limited financial and human capital, potentially reinforcing rather than reducing digital inequalities. Given these complexities, a fundamental question arises:

> **RQ7.** *How do firm size and regional disparities shape the evolution of digital access, skills, and usage, and what mechanisms prevent firms from transitioning from basic access to full digital integration?*

Different industries exhibit unique digital adoption patterns due to variations in technological needs, market pressures, and workforce capabilities. While ICT-intensive firms tend to integrate digital tools seamlessly, industrial and service sectors face greater difficulties in closing the skills gap and adapting to digital business models. This sectoral divergence suggests that the ability to transition from foundational digital infrastructure to more advanced applications is neither automatic nor uniform. Instead, firm-level capabilities and external market conditions interact in ways that can reinforce existing disparities. This leads to a critical inquiry:

> **RQ8.** *To what extent do sectoral characteristics and firm-specific capabilities determine the trajectory of digital adoption, and how do these factors contribute to persistent inequalities in digital integration?*

Many policy interventions have primarily focused on improving access to digital technologies, assuming that this alone will drive broader adoption and integration. However, without parallel investment in workforce development and organisational readiness, these measures may not produce the intended effects. If firms lack the necessary internal skills or strategic vision to integrate digital tools effectively, infrastructure improvements alone could simply widen existing disparities. Considering this, it becomes necessary to ask:

> **RQ9.** *What types of policy interventions can effectively bridge the second-level digital divide, ensuring that access improvements translate into meaningful skill development and technology integration rather than reinforcing existing inequalities?*

This study employs a repeated cross-sectional strategy to achieve these objectives, address the research questions, and ensure robustness in consideration of the data’s inherent constraints.

Publicly available data from the ICT usage in enterprises survey conducted by ISTAT between 2014 and 2019 provides the foundation for analysis. The anonymised structure of the data restricts the ability to track individual firms' longitudinal dynamics, necessitating a focus on identifying overall trends. Consistent variables were carefully selected over the six years to ensure comparability and robustness, despite these constraints. Dimensionality reduction techniques, including Factor Analysis of Mixed Data (FAMD) and Multiple Correspondence Analysis (MCA), are utilised to derive composite indices for access, skills, and usage, capturing latent variables that represent firms' digital integration.

Although the anonymisation of firms limits the ability to trace individual-level dynamics over time, the aggregated data allow for identifying trends across firm sizes, sectors, and regions. To measure and visualise inequality trends, the Gini coefficient is applied to the composite indices, quantifying disparities in access, skills, and usage. Line graphs will illustrate the Gini coefficients over the six years, highlighting the evolution of digital inequalities among different groups. This methodological approach directly addresses the research questions by identifying evolving patterns in digital adoption and linking them to structural inequalities. The findings aim to inform policy interventions by pinpointing areas where resources and strategies are most needed to promote equitable digital transformation.

This study contributes to the literature on the digital divide by providing fresh insights into the complexities of digital technology adoption among Italian firms. By employing the RTIF, it highlights how disparities in access, skills, and usage interact dynamically to shape digital integration at the firm level. This framework enables a nuanced analysis of digital inequalities by accounting for contextual factors, resource allocation, firm-specific characteristics, and external influences, such as institutional policies and technological disruptions, which collectively shape technology adoption. The findings reveal a persistent skills gap among different groups, providing empirical evidence to inform targeted policy interventions that aim to foster a more inclusive digital landscape.

This chapter unfolds systematically, beginning with an introduction delineating the study's significance and objectives. It proceeds with a comprehensive literature review and a theoretical framework, which explores the digital divide and introduces the Resources and Technology Integration Framework (RTIF) as the conceptual basis for the analysis. Before detailing the empirical strategy, the chapter presents a contextualisation of Italy's digitalisation landscape between 2014 and 2019. This section situates the Italian case within its broader institutional, market, and innovation environment, drawing on complementary evidence to interpret the empirical findings through the lens of the RTIF framework. The methodology section follows, outlining the analytical approach and dataset used. The results section then presents key findings on disparities in access, skills, and usage of digital technologies across firm sizes, sectors, and regions. The chapter concludes by synthesising these insights, discussing their policy relevance, and suggesting pathways for addressing persistent inequalities in digital adoption. Supplementary materials, including detailed variable definitions, robustness checks, and extended tables and figures, are provided in the appendices to support the methodological and empirical analyses.

4.2. Literature Review

The digital divide was initially conceptualised to highlight disparities in access to digital technologies among individuals, households, and demographic groups, focusing on computing technologies and connectivity, known as the first level (Norris, 2001; van Dijk, 2020; van Dijk & Hacker, 2003). As the understanding of the digital divide evolved, scholars recognised that it also encompassed disparities in digital skills and technology usage, expanding the concept to include proficiency and frequency of use as the second level (Hargittai, 2002; van Deursen & van Dijk, 2011; van Dijk, 2005). While the discourse has evolved to consider a third level, which examines the varied outcomes resulting from differences in access, skills, and usage (Ragnedda, 2017; Scheerder et al., 2017; Van Deursen & Helsper, 2018; Wei et al., 2011), this study will focus on the disparities at the first and second levels. This approach to understanding the digital divide reveals the complexity of digital inclusion and its critical implications for societal and economic participation.

van Dijk and Hacker (2003) have described the digital divide as a complex and dynamic phenomenon, reflecting its evolution, the pervasiveness and sophistication of digital technologies, and the intricate interactions with preexisting inequalities. This concept has expanded to include analyses at the macro and micro levels. At the macro level, research by Innegbedion (2021), Mutula (2008), Ferro et al. (2005), Billon et al. (2009), Chipeva et al. (2018), Ono and Zavodny (2007), Lamberti et al. (2023), and Vicente and Lopez (2011) have examined the digital divide regionally and internationally, underscoring the global extent of digital disparities and the exacerbating effect of socioeconomic factors such as income, education, and employment. At the regional scale in Italy, Lasagni et al (2015) show that institutional quality is closely associated with firm productivity, while Nifo and Vecchione (2014) highlight how weak institutions in the South have also contributed to skilled migration outflows. These findings demonstrate how institutional asymmetries intersect with digital divides, thereby reinforcing regional disparities in economic performance.

On the contrary, microlevel studies by van Dijk and Hacker (2003), Ragnedda (2017), Ragnedda and Muschert (2013), and van Deursen and van Dijk (2014) have argued that the digital divide is explained not only by socioeconomic differences but also by demographic features. These analyses have traditionally focused on individuals and households as the primary units of analysis (Aissaoui, 2021; Hanafizadeh et al., 2013; Lythreatis et al., 2022).

While there is extensive literature overlapping with the digital divide at the firm level, such as information systems, digital transformation and technology adoption at the firm level, these fields have established robust theoretical frameworks like the Diffusion of Innovations (DOI), Technology-Organisation-Environment (TOE) framework, and the Technology Acceptance Model (TAM), offering valuable insights into the process of digital technology adoption among firms. However, the extensive literature on digital transformation and technology adoption has focused mainly on the effects on firm performance, productivity, and innovation, rather than the underlying mechanisms that contribute to digital disparities at the firm level.

The need for more detailed exploration at the firm level is underscored by Shakina (2021), Bach et al. (Bach et al., 2013), Lythreatis et al. (2022), Acilar et al. (2021), Thonipara et al. (2023), Siqueira et al. (2019), and Riggins and Dewan (2005). These authors argue for a deeper investigation into how firms, key drivers of economic activity, interact with digital disparities. Such a granular approach aims to elucidate the multifaceted challenges and opportunities digital technologies present to businesses of different sizes and across various sectors and regions, pinpointing a critical gap in the existing literature. Empirical studies in Italy already point in this direction: Fabiani et al (2005) show that ICT adoption is strongly conditioned by firm size, workforce human capital, and the local industrial environment, while Bloom et al (2012) highlight the importance of managerial practices for realising the productivity benefits of IT. These contributions suggest that firm-level digital divides cannot be reduced to access alone, but also depend on internal organisational capabilities and the external institutional setting.

Cirera et al. (2022) argue that the emergence of digital technologies has prompted researchers to measure their adoption and impact at the firm level. However, one of the primary barriers to conducting such research is the limited availability of firm-level microdata. Despite initiatives such as the Digital Economy and Society Index (DESI) developed by Eurostat, existing measures remain insufficient for capturing the full scope of technologies that firms use. This is largely because available data are often aggregated at the macro level, usually at the country level, rather than providing detailed insights into firm-level adoption patterns.

4.3. Theoretical framework

The RTIF, developed in Chapter 3, is an adaptation of van Dijk's original Resources and Appropriation Theory (RAT), which was initially designed to examine digital divides at the individual and household levels. The RTIF, as depicted in Figure 26, extends the scope to organisational contexts, addressing the complexities of digital disparities within firms. This framework reinterprets key constructs, access, skills, and usage, while incorporating additional contextual constructs such as firm heterogeneities (e.g., size, age, and technological endowments) and contextual strategic positioning (e.g., sector, location, and supply chain roles). It also emphasises the influence of external forces, including regulatory environments, technological disruptions, and institutional frameworks.

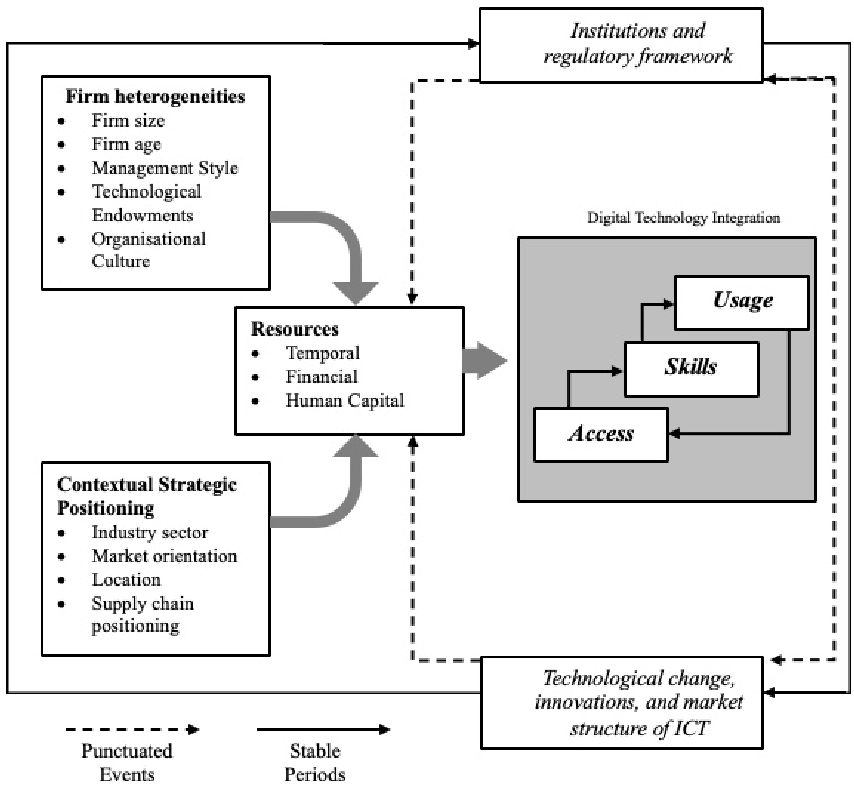

Figure 26: Conceptual Map of the Resources and Technology Integration Framework. Source: Adaptation from van Dijk (2005; 2020).

The RTIF offers a different explanation that extends beyond the scope of other traditional theoretical models, such as the Diffusion of Innovations (DOI) (Rogers, 1995), the Technology

Acceptance Model (TAM) (Venkatesh et al., 2003), and the Technology-Organisation-Environment (TOE) framework (Tornatzky et al., 1990). Although DOI primarily explains how technology spreads through populations and at what rate, it fails to address the resource-based barriers that firms encounter during technology integration. Similarly, TAM provides valuable insights into user acceptance based on perceived ease of use and usefulness, but does not encompass the broader organisational and environmental factors that influence technology deployment. The TOE framework offers a balanced perspective considering technological, organisational, and environmental contexts, yet it lacks the granularity needed to understand ongoing technology utilisation and integrations within firms.

The theoretical foundation for this study is the RTIF, as detailed in Chapter 3. The framework conceptualises digital integration at the firm level through three interdependent constructs: access, skills, and usage, shaped by contextual and resource-based factors. Figure 26 illustrates the intricate relationships between these constructs, contextual influences, and resource allocation. Figure 27 depicts the digital technology stack, which progresses from foundational tools, such as ERP and CRM systems, to advanced applications, including AI and data analytics. Due to data availability, this chapter focuses specifically on foundational technologies, corresponding to the light grey section of the digital technology stack in Figure 27. This approach enables a detailed examination of the initial stages of digital integration, providing insights into how firms establish their technological foundation.

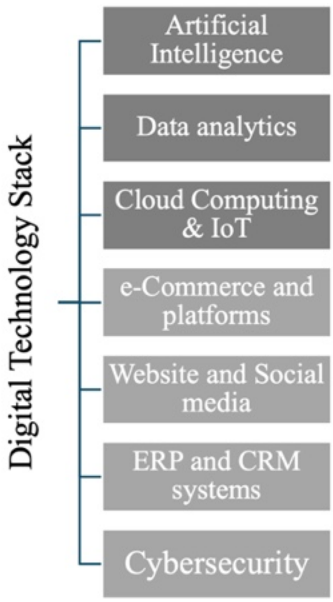

Figure 27: Digital Technology Stack.

Foundational technologies are represented in light grey, and advanced technologies are in dark grey.

Source: Adapted from Siebel (2019).

4.4. Structural and Institutional Context of Italy's Digitalisation

To effectively implement the RTIF introduced in the previous section, this study provides a more detailed examination of the Italian context. Italy presents a particularly instructive empirical setting due to its structural asymmetries, institutional disparities, and regional divides in the adoption of digital technology. Contextualising the broader structural, institutional, and market landscape that influenced digitalisation during the 2014–2019 period helps to interpret the empirical findings that follow and offers insight into the conditions shaping Italy's digital transformation. While many structural patterns extend beyond this window, the selected timeframe offers meaningful insights into ongoing disparities.

The Italian market for digital technologies has exhibited characteristics aligned with an oligopolistic structure. A small number of global firms, primarily based in the United States, control key segments, including cloud services, enterprise software, and data infrastructure. Amazon Web Services, Microsoft Azure, and Google Cloud rapidly expanded their presence across Europe, including Italy, by offering scalable and integrated digital solutions.

In parallel, domestic providers such as Aruba.it, TIM/Noovle, and Engineering S.p.A. served specific market segments, including SMEs, public administration, and defence. However, these actors faced structural disadvantages when competing against multinational firms, particularly due to network effects, reputational dominance, and economies of scale. This created a situation of asymmetric competition, where Italian firms functioned more as adapters or integrators of global technologies than as direct competitors. These dynamics not only reflect the Schumpeterian model of innovation led by dominant incumbents but also align with broader perspectives on technological dependency and centre–periphery relations (Calvino, 2019; Leydesdorff & Cucco, 2018). Italy's digital trajectory during this period was shaped by structural asymmetries that limited its capacity to act as an autonomous innovator, leading it to function primarily as an adopter of foreign digital platforms within an increasingly globalised digital economy (European Investment Bank, 2021).

On the demand side, the Italian economy displayed a dual-speed digital transformation. Larger firms and industrial regions in the north adopted digital technologies at a faster pace, particularly in manufacturing, creative industries and ICT-intensive sectors. Data from ISTAT surveys confirm that cloud computing, CRM systems, and e-commerce were more prevalent among firms in regions such as Lombardy and Emilia-Romagna (European Investment Bank, 2021). These patterns can be interpreted through the lens of what Dosi et al. (2018) describe as a form of "neodualism" within the Italian productive system, whereby a small group of highly productive firms adopt digital technologies at scale, while a much larger segment of firms remain stuck in low-skill, low-capability trajectories. This dual structure reflects persistent disparities in organisational capabilities and training systems, which limit firms' ability to engage in digital transformation. These challenges are further shaped by broader structural factors such as uneven infrastructure deployment and institutional asymmetries that influence regional digital readiness and reinforce existing divides. Ongoing inequalities in digital usage and capabilities across the country highlight deeper systemic patterns embedded within Italy's regional innovation systems and institutional landscape (Benecchi et al., 2023; Leydesdorff, 2021).

Beyond infrastructure and firm-level constraints, institutional quality played a crucial role in shaping the regional landscape of digital technology adoption. Data from the Institutional Quality Index (IQI)[4] reveal stark and persistent disparities across Italy's macro-regions from 2014 to 2019. Northern regions, such as the Northeast, Northwest, and Centre, consistently scored above 0.65 on the weighted IQI, while the South and Insular areas remained below 0.35 as shown in Table 11. These institutional asymmetries affect public services, regulatory quality, and trust in government, shaping incentives and constraints for firms adopting digital technologies.

NUTS1	2014	2015	2016	2017	2018	2019
Northwest	0.78	0.76	0.73	0.71	0.75	0.74
Northeast	0.87	0.85	0.82	0.81	0.83	0.82
Center	0.69	0.71	0.69	0.65	0.68	0.66
South	0.33	0.36	0.33	0.31	0.34	0.32
Insular	0.25	0.28	0.24	0.22	0.24	0.22

Table 11: Institutional Quality Index (IQI) by Macro-Region (NUTS 1), 2014–2019.
Weighted IQI scores indicating institutional quality across Italian macro-regions.
Source: Nifo and *Vecchione (2014).*

Nifo (2014) provides further evidence by linking uneven institutional quality to the migration of skilled individuals from southern regions, thereby exacerbating regional skill shortages. These skill outflows constrain the internal capabilities of firms and public institutions to engage effectively with digital transformation. In response, several policy interventions were

[4] The Institutional Quality Index (IQI), developed by Nifo and Vecchione (2014), measures institutional quality in Italian provinces and regions across five dimensions: voice and accountability, government effectiveness, regulatory quality, rule of law, and corruption. It uses various data sources and covers the years 2004–2019.

introduced to address these institutional and regional disparities. As summarised in Table 12, a set of policy interventions was implemented at the EU, national, and regional levels during the period, several of which had direct or indirect implications for addressing the digital divide among Italian enterprises. These initiatives include the PON Imprese e Competitività (ERDF), Voucher Innovation Manager, and Credito d'imposta Formazione 4.0, which aim to promote digital skills and technology adoption through place-based mechanisms, particularly targeting Southern Italy.

Level	Policy / Regulation	Period	Constructs	Mechanism & National Relevance
EU	WTO Information Technology Agreement (ITA)	1997–ongoing	Access	Eliminates tariffs on ICT goods, reducing the cost of importing digital equipment and infrastructure.
EU	EU Free Trade Agreements (FTAs)	2015 (S.Korea), 2019 (Japan), etc.	Access	Reduces non-tariff barriers and tech product tariffs, facilitating ICT imports and technology adoption.
EU	GDPR – General Data Protection Regulation	2016 (Issiued) / Enforced 2018	Usage	Introduces data privacy and processing rules, raising compliance costs but increasing trust in digital services.
EU	eIDAS Regulation	2014–ongoing	Usage	Establishes a trust services and digital signature framework, facilitating secure digital transactions.
EU	Digital Services Tax (DST)	Proposed at EU, adopted by Italy in 2020	Usage	Imposes a 3% tax on platform services, potentially affecting SME incentives to advertise or sell online.
Italy	Piano BUL – Banda Ultra Larga	2015–ongoing	Access	Public investment in broadband infrastructure, helping reduce the geographic digital divide, especially in rural areas.
Italy	Iperammortamento / Superammortamento	2017–2019	Access, Usage	Offers tax deductions on capital goods (digital tech), incentivising investment in equipment and software.
Italy	Credito d'imposta Formazione 4.0	2018–2020	Skills	Provides tax credits for digital skills training, supporting digital capacity development in firms.
Italy	Voucher Innovation Manager	2019–2020	Skills, Usage	Grants to hire digital transformation experts, boosting absorptive capacity and strategic integration of technologies.
Local	PON Imprese e Competitività (ERDF)	2014–2020	Access, Skills	Regional investment co-financed by the EU, targeting Southern Italy and reducing regional digital disparities.

Table 12: Overview of EU and National Policy Instruments Supporting Digital Adoption.

Italy played a relatively selective role in shaping digital innovations. Its most notable contributions were concentrated in industrial automation and mechatronics, particularly in the application of robotics and digital tools within advanced manufacturing. This downstream strength reflects the ability of some Italian firms, particularly those in regions such as Emilia-Romagna and Lombardy, to integrate digital solutions into their traditional production systems. However, these successes coexist with significant gaps across other sectors and regions, contributing to a structural divergence between digital frontrunners and firms with limited capabilities. At the same time, frontier technologies such as artificial intelligence, big data, cloud computing, e-commerce platforms, and social media ecosystems were predominantly developed by multinational corporations based in the United States and China. Italy's contribution to these frontier domains was limited, although it demonstrated notable strengths in strategic areas such as quantum computing and semiconductors, supported by strong research capabilities and industrial specialisation (European Commission, 2025).

Despite these strengths, the diffusion of frontier digital technologies among firms remained uneven. While 70.2% of Italian SMEs had reached at least a basic level of digital intensity, only 8.2% had adopted artificial intelligence, underscoring the gap between foundational uptake and advanced technological integration (European Commission, 2025). Initiatives such as the Industry 4.0 plan (Piano Nazionale Impresa 4.0), launched in 2016, aimed to address this divide by offering fiscal incentives for digital adoption among SMEs (Ministero dello Sviluppo Economico, 2017). Italy's trajectory, therefore, reflects a hybrid profile: a country capable of contributing to strategic technologies while still facing structural limitations in the broad-based deployment of advanced digital tools.

Even before digital sovereignty became a core element of the European digital agenda after 2020, concerns about technological dependency were already present. Italian enterprises and public institutions relied increasingly on non-EU providers for cloud infrastructure, software services, and platform access. National digital initiatives, such as SPID (digital identity) and PagoPA (e-payment systems), gained visibility; however, the broader digital ecosystem continued to exhibit a structural dependence on foreign technology (European Commission, 2019).

Italy's reliance on external providers for critical digital infrastructures is part of a broader European pattern of technological dependency. These dependencies reflect the global concentration of digital markets, the scale and network advantages of leading multinational providers, and long-standing constraints in Italy's capacity to independently develop and scale digital technologies. A notable example is Huawei's involvement in Italy's early 5G rollout, an arrangement that enabled faster deployment but later raised concerns about data governance, surveillance, and digital sovereignty (Negro, 2024). These dynamics have contributed to increasing awareness of the need for stronger governance responses, which at the EU level have taken shape through the Digital Markets Act, the Digital Services Act, and the AI Act (Madiega, 2020; Falkner et al., 2024). Although these policy interventions came after the 2014–2019 period, they address dependencies and risks that were already visible during those years and remain relevant for interpreting patterns of digital adoption and disparity.

The analysis of market structure, institutional capacity, and external dependencies, provides a critical context for interpreting the digital divide across Italian enterprises. The results presented in section 1.6, which examine access, skills, and usage, are not merely outcomes of internal firm decisions. They are deeply embedded in a broader configuration of platform concentration, fragmented domestic demand, persistent regional and institutional asymmetries, and structural dependencies. Recognising these dynamics allows for a more comprehensive understanding of why digital inequalities persist and why some firms and regions remain systematically behind.

4.5. Methodology

Before delving into the methodology, it is essential to ensure transparency and enable replicability. All study materials, including the handling of missing data, weight calculations, additional statistics, results, and robustness checks, are publicly available in a GitHub repository named "*Factor_Analysis_Digital_Divide*."

This study draws on publicly available data from the ICT Usage in Enterprises Survey conducted by ISTAT between 2014 and 2019. The dataset provides rich and detailed information on firms' digital technology adoption across different sizes, sectors, and regions, making it well-suited for analysing patterns of digital inequality. To ensure temporal comparability, only variables that remained consistent across all six years were selected. As detailed in Table 13, these variables correspond to the three core constructs of the RTIF framework: access, skills, and usage, which serve as the analytical foundation for assessing the digital divide among Italian firms.

The decision to employ a repeated cross-sectional (RCS) design in this research is primarily driven by data availability and the regulatory constraints set by ISTAT, the Italian National Institute of Statistics. Due to ISTAT's policies on sharing micro-level data, the data provided is anonymised to protect the privacy and confidentiality of the participating companies. This anonymisation process prevents tracking or linking specific companies across different years, necessitating an independent cross-sectional approach for each year's data. The use of RCS design has been predominantly applied in health sciences (Pan, 2021). However, this methodology has also been effectively used in other fields, such as business and management (Disegna et al., 2018; Doering et al., 2019), education studies (Almond & Sinharay, 2012), and social sciences (Butler et al., 2022). To ensure the robustness of this approach, the checklist suggested by Rafferty et al. (2015) was followed to prepare the data for repeated cross-sectional analysis.

Using RCS data to analyse the adoption of digital technologies among Italian firms requires several critical assumptions. These include the consistency of the survey design over different years, the homogeneity of the surveyed population, and the temporal independence of the samples (Doering et al., 2019). Such assumptions ensure that the data collected at various points in time are comparable and that any observed variations reflect genuine changes in digital adoption patterns rather than anomalies of the data collection process. Despite the inherent limitations of this approach, particularly its inability to track individual firms over time and its constraint in making causal inferences, the methodology offers significant advantages. It can produce representative snapshots that uncover patterns of change in overall levels of digital technology integration each year.

The variables in Table 13 are classified into three main groups: access, skills, and usage. Access variables include continuous and binary measures assessing access to computing technologies and internet connectivity, as well as a proxy representing incentives for companies to promote the use of digital technologies through ICT training. Skills are measured through binary variables indicating the digital capabilities of firms, including training initiatives and the employment of in-house personnel for ICT-related tasks. Usage variables, also binary, capture the extent to which firms utilise digital technologies for various business functions such as management, marketing, and commerce. This encompasses the foundational stack of technologies like management systems (ERP and CRM), websites, social media, and digital platforms.

According to the taxonomy proposed by Cirera et al. (2022), these digital technologies are considered cross-cutting tools that can be applied to general business functions, irrespective of the specific economic sector. Their role is foundational, enabling a wide range of organisational processes and productivity improvements. While the present analysis centres on these foundational digital technologies as illustrated in Figure 27, it also establishes the groundwork for understanding the adoption of more advanced tools. These include artificial intelligence, machine learning, business analytics, and cloud computing, which typically build upon the basic infrastructure assessed in this study.

Variable Names (Mixed variables)	**Composite Index - First-level Digital Divide**
Percentage of employees using the computer out of total employees (C)	**Access**
IT training courses for employees without specialist ICT skills (B)	
Percentage of employees using computers connected to the internet (C)	
Enterprise provides mobile devices with mobile connection (B)	
Low Internet download speed (B)	
High Internet download speed (B)	
Three dummies representing firm size by revenue (small- medium - large)	
Variable name (Binary variables)	**Composite Indices - Second-Level Digital Divide**
Employment of specialists in computer subjects	**Digital Skills**
IT training courses for employees with specialist ICT skills	
Use of internal personnel for ICT infrastructure maintenance	
Use of internal personnel for office software support	
Use of internal personnel for enterprise software development	
Use of internal personnel for enterprise software support	
Use of internal personnel for web development	
Use of internal personnel for web development support	
Use of internal personnel for IT security management	
Three dummies representing firm size by revenue (small- medium - large)	
Use of the website	**Digital Technology Usage**
Possibility to place orders or reservations online, e.g., online shopping cart.	

Access to product catalogues or price lists	
Links or references to company profiles on social media	
Use of Social Networks	
Use of social media and multimedia	
Using ERP software	
Use operational CRM software	
Use analytical CRM software	
Announcement of vacancies or possibility to apply for employment online	
Web sales through intermediary websites or e-Commerce sites marketplaces or apps	
Three dummies representing firm size by revenue (small- medium - large)	

Table 13: Group of variables by composite index.

Source: ICT usage in enterprises, ISTAT. (C) Continuous variable. (B) Binary variable.

This study employed 29 variables to extract three factors that represent the theoretical constructs: six variables for the access index, nine variables for the skills index, and eleven variables for the usage index (see Appendix B). Additionally, each index contains three active variables, represented by dummies for firm size (small, medium, and large).

To ensure the robustness of the composite indices and to evaluate the methodological implications of including firm size as an active variable in the factor extraction process, a sensitivity check was performed. Specifically, the same factor analysis procedures were replicated without including the firm size dummies as active variables. This comparison enabled us to determine whether the inclusion of firm size significantly influenced the indices. The results indicate that while the Skills and Usage indices remained relatively stable across both specifications, the Access index showed greater sensitivity to the inclusion of firm size. This finding is consistent with the view that access-related variables such as infrastructure, connectivity, and equipment may be more directly shaped by firm size and related resource capacities (see Appendix E).

Additionally, to ensure consistency across all variables over the years, imputation techniques were applied to facilitate the ongoing analysis. Two primary methods were utilised: multivariate imputation using the MICE package in R and stratified imputation. These approaches were essential for maintaining data integrity and continuity. A detailed review of the imputation methodologies and their application can be found in Appendix A.

Assuming the independence of each year's sample in the repeated cross-sectional (RCS) design, ANOVA and Chi-square tests were conducted. These tests confirmed the independence of samples across different years (see Appendix C for further details). Additionally, internal consistency and reliability tests were performed on each dataset before applying dimensionality reduction techniques. The Cronbach's alpha values ranged from 0.71 to 0.87, indicating a high level of acceptability for factor analysis. For a comprehensive review of the tests conducted before factor analysis, refer to Appendix B.

The core constructs of the theory were operationalised as follows: access, which is represented by a mix of continuous and binary variables, was analysed using Factor Analysis for Mixed Data (FAMD), while skills and usage, defined solely by binary variables, were analysed using Multiple Correspondence Analysis (MCA), as detailed in Table 13. Before extracting the factors, weights were calculated (see Appendix B) to account for variations in sample sizes across different groups, including year, region, revenue levels, sectors, and firm sizes. These weights were then applied to the FAMD and MCA functions to ensure that the analyses accurately reflected the distribution and importance of each subgroup within the dataset.

FAMD was selected because of its capability to handle datasets containing both numerical and categorical variables, making it particularly suitable for constructing the access index. This method, first proposed by Pagès and Camiz (2008), integrates the principles of principal component analysis (PCA) for numerical data and multiple correspondence analysis (MCA) for categorical data. It is predominantly utilised in fields where mixed data types are common, such as social sciences and marketing research. Conversely, MCA was chosen for the skills and usage indices due to its effectiveness in analysing and visualising relationships between categorical variables. Introduced by Benzécri (1973), MCA identifies patterns and associations among categorical variables, translating them into smaller dimensions. It is widely used in sociology and epidemiology.

Mathematically, the indices are represented as follows:

$$Access\ Index_i = \sum_{j=1}^{9} a_j \cdot X_{j,i} \cdot w_i$$

$$Skills\ Index_i = \sum_{k=1}^{11} b_k \cdot Y_{k,i} \cdot w_i$$

$$Usage\ Index_i = \sum_{m=1}^{14} c_m \cdot Z_{m,i} \cdot w_i$$

Where: X, Y and Z are the matrices of observations for access, skills, and usage variables, respectively, including the firm-size dummies for each index. a, b and c are the vectors of weights derived from FAMD and MCA contributions of each variable to the retained dimensions. w is the vector of weights accounting for the share of groups and years. The indices j, k and m represent the variables within each construct (access, skills, and usage). These equations denote the aggregation of the weighted variables for each index.

The factor extraction was conducted using the FactoMineR package in R, a powerful tool for multivariate data analysis. This selection of methods, along with the application of calculated weights, ensured that the indices were robust and accurately reflected the underlying constructs. The results, including eigenvalues, scree plots, and the contributions of each variable to the indices, are detailed in Appendix D. These visualisations and metrics provide a comprehensive overview of the factor structures and their explanatory power, underpinning the validity of the constructed indices across the studied years.

While factor analysis captures the underlying structure and variation of these constructs, the Gini index offers a complementary perspective by quantifying the degree of inequality within and across groups. This dual approach enables a deeper understanding of not only the presence of digital disparities but also their distribution across firms of varying sizes, sectors, and regions. The Gini index, initially developed by Corrado Gini in 1912, is a widely used statistical measure of inequality within a distribution. Its primary purpose is to quantify disparities by assessing the deviation from perfect equality, where all observations would have identical values. The Gini index ranges from 0 (indicating perfect equality) to 1 (representing maximum inequality). While historically associated with income distribution (Cowell, 2011), the Gini index has been applied in diverse contexts, including health outcomes (Abatemarco et al., 2024), educational access (Bennett, 2011), and digital inequalities at the regional level (Fidan, 2017).

The Gini index is calculated using the following formula:

$$Gini = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left| x_i - x_j \right|}{2 \cdot n \cdot \sum_{i=1}^{n} x_i}$$

Where x_i and x_j are the values of the variable under analysis (e.g., access, skills, or usage) for observations i and j. The total number of observations is denoted by n. The numerator

$\sum_{i=1}^{n}\sum_{j=1}^{n}|x_i - x_j|$ represents the sum of pairwise absolute differences between all observations, reflecting the extent of inequality. The denominator $2 \cdot n \cdot \sum_{i=1}^{n} x_i$ normalises the differences, ensuring that the index ranges between 0 and 1.

The Gini index is particularly well-suited for examining the digital divide because it captures disparities within constructs that are inherently unequal, such as access to digital infrastructure, availability of ICT skills, and the usage of digital technologies. Digital inequalities are multidimensional and vary significantly across firms, sectors, and regions. By applying the Gini this analysis highlights not only the existence of disparities but also their magnitude and evolution over time. Furthermore, the application of the Gini index to subgroups, such as SMEs, large firms, sectors, and regions, enables a comparative analysis that is critical for understanding structural inequalities. For instance, SMEs may exhibit higher skill disparities compared to large firms, while specific regions may lag in access to digital infrastructure. Such insight is essential for policymakers aiming to address these inequalities and for firms aiming to benchmark their digital maturity.

4.6. Results

The results section addresses the primary objectives and research questions of this study by examining disparities in digital technology integration among Italian firms. It analyses how access, skills, and usage have evolved over time and employs the Gini coefficient to capture inequalities within these constructs. In line with the RTIF framework introduced in Chapter 3, the analysis also considers how access, skills, and usage interact, exploring whether improvements in infrastructure are matched by capability development and effective usage.

To provide a comprehensive view of digital integration, the section adopts a dual analytical approach. It presents both Gini indices, which quantify structural inequalities across firms, and normalised median values (reported in Appendix D), which capture overall progress. This combination highlights where digital adoption has advanced despite persistent disparities, and where improvements have remained unevenly distributed.

The results are then disaggregated by firm size (SMEs vs. large firms), macro-sector (industrial, commercial, services, creative industries, and ICT), and region (NUTS 1), in order to assess how organisational resources, institutional environments, and sectoral or territorial contexts shape patterns of digital integration. This strategy allows the RTIF's core assumptions to be examined across different settings, showing how access, skills, and usage disparities evolve under varying structural and institutional conditions.

4.6.1. Yearly Trends in Gini Indices

Figure 28 shows annual trends in the Gini indices related to three key aspects: access, skills, and usage of digital technologies. These indices quantify disparities in the adoption of digital technologies among Italian firms over the observed timeframe. Analysing these trends provides insight into the levels of digital inclusion and the persistence of inequalities in the Italian business landscape.

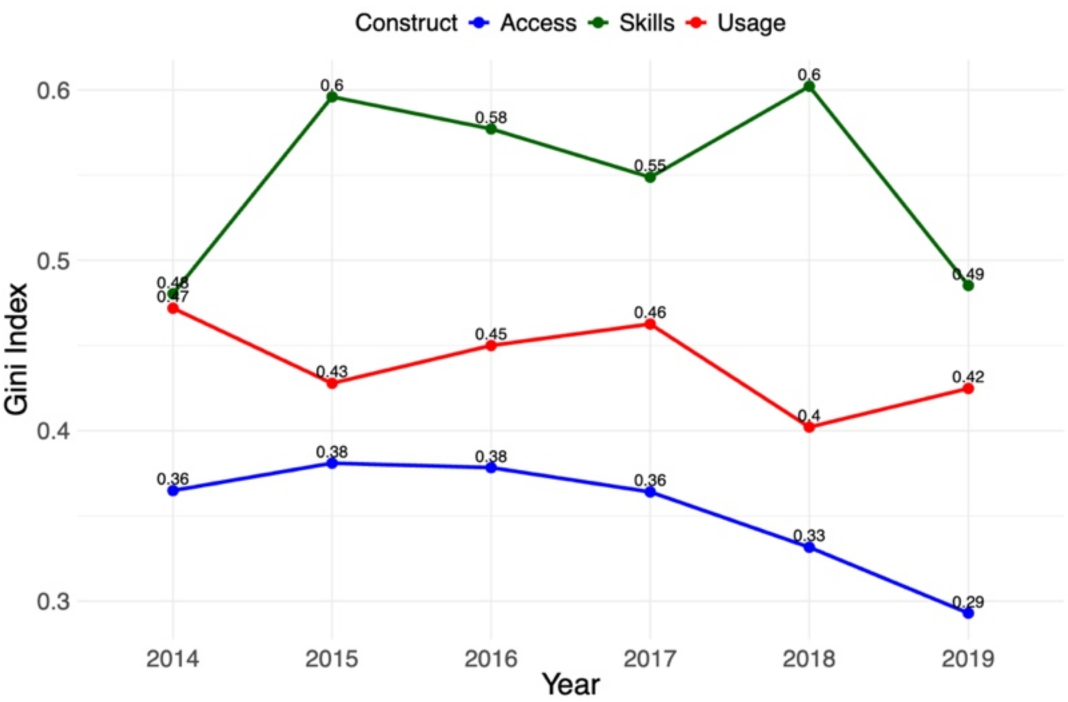

Figure 28: Yearly Trends in Digital Access, Skills, and Usage Among Italian Firms (2014-2019). Source: Author's Elaboration.

The access index demonstrates a consistent decline in disparities, starting at 0.36 in 2014 and reaching 0.29 by 2019. This suggests progress in the diffusion of foundational digital infrastructure, such as internet connectivity and computing technologies. The sharper decline observed from 2017 onwards coincides with the implementation of fiscal measures under the 2016 Italian Budget Law (Law n. 232/2016), which included the *iperammortamento* incentive. This programme offered substantial tax benefits for investment in high-tech machinery and ICT equipment and is reported to have stimulated investment in digital capital goods (Bratta et al., 2020). While no direct causal link can be established between the Gini results and the findings here, the overlap in timing is consistent with evaluations that highlight increased adoption during this period. More broadly, the pattern of improving access aligns with national-level policy assessments. According to the Digital Economy and Society Index (DESI 2022), Italy achieved notable gains in digital infrastructure and public services, even if challenges remained in SME digitalisation and skills (European Commission, 2022). Although DESI extends beyond the timeframe of this study, it reinforces the interpretation that access-related inequalities narrowed during the observed period.

The skills index shows a more variable trajectory, with relatively higher levels of inequality compared to access. Starting at 0.48 in 2014, the Gini coefficient for skills peaks at 0.60 in 2015 and again in 2018, before decreasing slightly to 0.49 in 2019. This fluctuation highlights the difficulty of achieving balanced progress in workforce capabilities across firms. These findings are consistent with the Italian government's National Strategy for Digital Skills, which pointed to mismatches between graduate supply and labour market demand. The Digital Skills Observatory (Osservatorio Competenze Digitali, 2021), a joint initiative by Assintel, Anitec-Assinform, and AICA, estimated in 2019 that, despite growing enrollments in computer science degrees, the national economy faced a shortage of approximately 15 thousand ICT graduates. The persistent inequality indicated in the Gini trends may reflect the uneven distribution of these scarce resources across regions and firm types, with larger or more urban firms better positioned to attract digital talent.

The usage index exhibits moderate variability. The Gini coefficient begins at 0.47 in 2014, declines to its lowest at 0.40 in 2018, and rises slightly to 0.42 by 2019. This pattern suggests incremental diffusion of digital tools for business operations, though adoption was neither linear nor uniform. The observed fluctuations may indicate that firms were adopting digital technologies to meet immediate operational needs but were limited in maximising their potential due to skill constraints. These results resonate with the RTIF interpretation that usage depends on prior access and skills: where capability development lags, usage remains uneven. This reinforces calls in the literature for strengthening workforce training and digital competencies as a precondition for deeper technological integration.

4.6.2. Analysis by Firm Size

Figure 29 illustrates these trends, offering a more specific view of how firm size relates to digital technology adoption. The access index for SMEs shows a consistent decline in disparities, with the Gini coefficient falling from 0.38 in 2014 to 0.31 in 2019. This suggests gradual convergence in access to digital infrastructure among smaller firms. Median values (Figure D2) also indicate an increase in overall uptake, rising from 0.28 to 0.48. Taken together, these observations suggest an improvement in the diffusion of infrastructure, although the limited decline in inequality implies that a significant segment of SMEs remains digitally marginalised. This pattern coincides with the period of fiscal incentives, such as the *iperammortamento*, which targeted capital investment in digital goods. However, the uneven reduction in disparities suggests that sectoral and regional heterogeneity continued to shape outcomes.

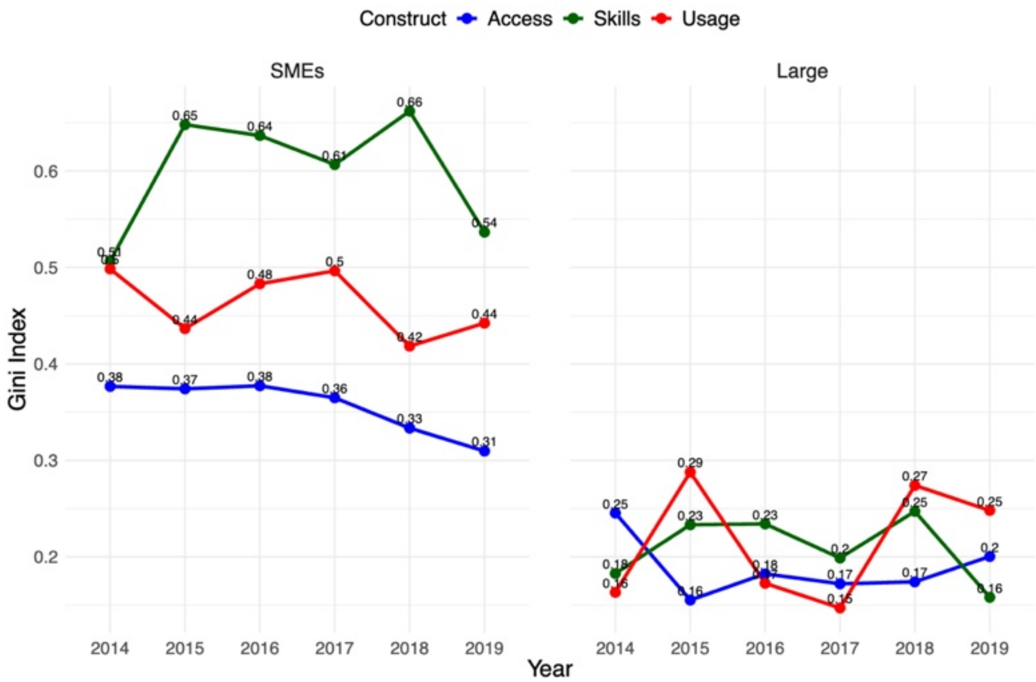

Figure 29: Yearly Trends in Digital Access, Skills, and Usage by Firms Size (2014-2019). Source: Author's Elaboration.

Among large firms, access disparities remain consistently low, with Gini coefficients stabilising between 0.25 and 0.20 throughout the observed period. This reflects the relatively uniform access to infrastructure enjoyed by larger enterprises, supported by their financial and operational resources. The median access values are also consistently high, ranging between 0.64 and 0.72, underscoring their already mature digital infrastructure. However, their flat trajectory suggests that the main challenges for large firms may lie less in basic infrastructure provision and more in system upgrades, legacy integration, or adoption of advanced technologies. This interpretation aligns with the broader context of Italy's structural dependency on foreign providers of cloud and platform services, which shaped the technological environment available to large enterprises during these years.

The skills index for SMEs exhibits persistent inequalities, with Gini coefficients starting at 0.51 in 2014, peaking at 0.66 in 2018, and declining slightly to 0.54 in 2019. This sustained high level of inequality highlights the challenges SMEs face in developing digital skills. Median values remained very low (below 0.15 in Figure D2), indicating that only a small subset of firms developed in-house digital capabilities, while the majority remained disconnected from skill formation. From an RTIF perspective, this points to a decoupling between access and skills, as improvements in infrastructure were not accompanied by widespread capability building. The limited reach of policies introduced toward the end of the period, such as the *Credito d'imposta Formazione 4.0* or the *Voucher Innovation Manager*, may help explain why skills remained unevenly distributed, particularly in regions with weaker institutional quality. However, no direct effect can be inferred without further analysis.

Large firms generally exhibit a lower skills divide compared to SMEs, benefiting from greater financial capacity and access to skilled personnel, particularly in metropolitan hubs such as Milan, Rome, and Turin. The low Gini indices and the higher medians (around 0.50) support this observation, suggesting that many large firms have institutionalised digital training and recruitment. Nonetheless, fluctuations in the Gini values indicate variability, which may be linked to differing sectoral needs or the periodic emergence of new technological demands (e.g., cybersecurity, AI integration).

The usage index for SMEs demonstrates a gradual decline in disparities over the observed period, with the Gini coefficient decreasing from 0.50 in 2014 to 0.44 in 2019. Median usage also increased, rising from 0.17 to 0.25, indicating incremental adoption of digital tools. However, this progress appears to be partially conditional: without a corresponding improvement in digital skills, many firms struggled to translate access into sustained and strategic use. This pattern supports the RTIF proposition that digital usage is contingent on both prior access and sufficient internal capabilities, particularly human capital and absorptive capacity.

The continued inequality in digital usage among SMEs may also reflect broader structural and institutional constraints, including uneven support ecosystems and limited exposure to digital transformation expertise. While initiatives such as the PON Imprese e Competitività (ERDF) provided targeted support, particularly in Southern Italy, their reach and long-term impact were shaped by existing disparities in institutional quality, regional coordination, and firm readiness. These findings are consistent with the broader institutional asymmetries discussed in Section 1.4 and underscore the importance of matching place-based digital policies with adequate implementation capacity. Rather than indicating the ineffectiveness of the policy itself, the results suggest that policy uptake and outcomes are conditioned by regional and organisational contexts, in line with the RTIF's emphasis on the interaction between internal resources and external enabling environments.

In contrast, large firms exhibit significantly lower disparities in usage, with Gini coefficients fluctuating moderately over time. Peaks (e.g., 0.29 in 2015) and troughs (0.15 in 2017) may reflect initial experimentation with new digital tools, variation across sectors, or organisational challenges in scaling technologies. However, the subsequent rise in inequality—from 0.15 in 2017 to 0.27 in 2018, and a slight decrease to 0.25 in 2019—suggests a phase of differentiated digital consolidation. While some large firms have successfully integrated advanced digital solutions into their operations, others may have faced constraints from legacy systems, vendor lock-in, or uneven returns on prior investments. These dynamics likely reflect diverging technological strategies and absorptive capacities across sectors. Despite these fluctuations, consistently higher median values (above 0.50) indicate that many large firms had embedded digital tools into core functions. This profile aligns with the RTIF framework, illustrating how resource endowments and organisational readiness can mediate the translation of digital access and skills into practical usage.

These firm-level disparities also resonate with broader empirical findings on the economic benefits of digital adoption. Nucci et al. (2023) demonstrate, for example, that Italian firms that adopted digital technologies between 2015 and 2018 experienced higher productivity growth than those that did not. While their study focuses on aggregate performance outcomes, the present analysis complements this perspective by uncovering the underlying distributional patterns within the firm population. Specifically, the Gini-based results suggest that productivity gains may have been concentrated among a subset of digitally advanced firms, particularly large enterprises. In contrast, the majority of SMEs remained at the margins of this transformation. This interpretation is further supported by Cirillo et al. (2023), who find that advanced technologies (e.g. IoT, big data) are more prevalent in larger and manufacturing firms. Together, these findings reinforce the importance of complementing aggregate analyses with distribution-sensitive approaches, such as those employed here, to capture the stratified nature of digital transformation fully.

4.6.3. Macro Sector-Specific Digital Adoption Trends

Figure 30 presents the Gini coefficients for access, skills, and usage at the sectoral level, highlighting the degree of inequality in digital technology integration across sectors. In parallel,

Figure D3 in the appendix displays the median values of the same indices, capturing the central tendency and overall progression of digital adoption.

The industrial sector shows notable improvements in access, with Gini indices declining from 0.35 to 0.32 and the median rising from 0.25 to 0.42. This trend suggests that the diffusion of infrastructure and capital equipment became more balanced across firms in this sector. However, progress in capability development appears more limited: the skills index remains persistently high, with Gini values above 0.50 and median levels fluctuating between 0.13 and 0.16. Usage outcomes mirror this duality, with Gini values remaining moderate (~0.46) and median usage slightly declining, indicating that operational integration did not consistently follow infrastructure gains.

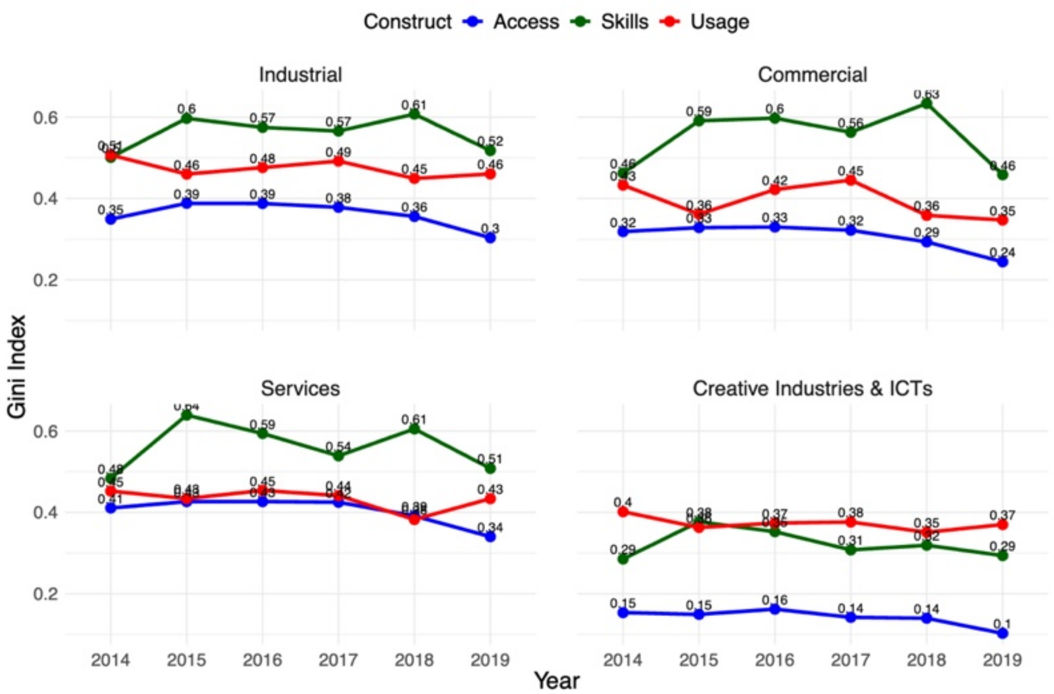

Figure 30:Yearly Trends in Digital Access, Skills, and Usage by Macro Sectors (2014-2019). Source: Author's Elaboration.

These findings refine the typical classification of manufacturing as a digitally intensive sector (Calvino et al., 2018), uncovering underlying disparities in internal capacities. As Serafini et al. (2025) argue, maturity in manufacturing often coexists with structural bottlenecks, particularly in workforce upskilling and the implementation of digital strategies. From a policy perspective, the positive trajectory in access is consistent with investment incentives such as iperammortamento, which Bratta et al. (2020) show contributed significantly to capital goods uptake in manufacturing. However, the persistence of skill and usage disparities points to a lag in complementary organisational change. While programmes like Credito d'imposta Formazione 4.0 aimed to address this challenge, their effectiveness was likely shaped by firms' absorptive capacity, sectoral inertia, and contextual conditions. These dynamics reinforce the RTIF insight that access alone does not ensure transformation; it must be supported by coordinated interventions across skills and usage dimensions, embedded within the structural and institutional ecosystem.

The commercial sector displays a more encouraging trajectory. Access becomes substantially more equitable, with Gini coefficients declining from 0.32 in 2014 to 0.24 in 2019, while the median nearly doubles from 0.29 to 0.60. Skills, however, continue to lag: Gini values remain high (around 0.60), and median scores range between 0.16 and 0.28. In 2019, some improvement is visible, as the Gini coefficient declines and medians rise, suggesting the beginning of a convergence process. This indicates that even limited skills were sufficient for the uptake of basic tools, such as e-commerce platforms and web presence. This supports Calvino et al. (2022), who note the extensive adoption of basic technologies in retail and wholesale but also highlight the limited penetration of advanced systems. EU-wide measures such as the *eIDAS Regulation* and the *GDPR* have shaped this environment by both strengthening consumer trust and raising compliance requirements. While this may have facilitated uptake among larger commercial actors, the uneven absorptive capacity of smaller firms may help explain the persistent divides observed in this context.

The services sector shows slower and more uneven progress compared to the manufacturing sector. While access inequality begins to decline after 2017 (from 0.42 to 0.34), with median access rising from 0.29 to 0.48, skills development remains stagnant, the Gini coefficient for skills hovers near 0.60, and median values do not exceed 0.18. This skill bottleneck helps explain why usage outcomes remain flat despite improved access to infrastructure. From an RTIF perspective, this highlights the critical role of internal capabilities, particularly workforce and managerial skills, in enabling firms to translate access into effective and sustained digital usage (Bloom et al., 2012).

Empirical studies corroborate this interpretation. Serafini et al. (2025) emphasise that the impact of innovation funding is highly uneven across service sub-sectors. Their study finds that while Knowledge-Intensive Services (KIS) benefited significantly*, "all the other services exhibit negligible impact,"* indicating persistent barriers to digital upgrading. Similarly, Calvino et al. (2022) attribute low levels of digitalisation in Italian service firms, especially micro and small enterprises, to a combination of limited skills, weak management capabilities, and low accumulation of intangible assets. These factors contribute to a growing gap between digitally advanced firms and the broader service sector, reinforcing the notion that the impact of digital policy is conditional on firms' readiness and absorptive capacity.

The creative industries and ICT sector exhibit a distinct profile compared to other sectors. Both demonstrate low inequality in access (Gini indices near 0.10 by 2019), suggesting a more advanced stage of digital maturity. Skills disparities are moderate but fluctuating, with Gini values ranging from 0.29 to 0.37 over the period. This suggests that while most firms in this group possess a baseline level of digital capability, there is still an uneven diffusion of more advanced skill sets, potentially linked to the integration of emerging technologies. Meanwhile, median usage declines from 0.41 to 0.30 by 2019, while usage inequality rises slightly (from 0.35 to 0.37). This trend may reflect a transitional dip associated with the shift from established digital systems such as ERP and basic CRM toward more complex, data-intensive solutions like AI, cloud-native architectures, and platform-based business models. From a theoretical standpoint, such patterns are consistent with the idea of capability reconfiguration proposed by Teece (2007), where organisations adjust routines, workflows, and investments to absorb and integrate new technologies. These reconfigurations may temporarily disrupt usage metrics as firms experiment, retrain staff, or phase out legacy systems. In this sense, the observed dip does not indicate digital stagnation but rather a strategic reorientation toward more advanced infrastructures, which may initially widen skills and usage gaps before they are consolidated.

These dynamics also unfold within a broader international and institutional ecosystem. Trade liberalisation through the WTO Information Technology Agreement (ITA) and EU Free Trade Agreements helped lower the cost of importing ICT goods, facilitating capital investment in ICT-intensive sectors. At the same time, Italy's structural reliance on non-EU providers such as Huawei's early role in 5G infrastructure (Negro, 2024) shaped the technology stack available to firms and influenced long-term strategic dependencies, particularly in cloud services, data security, and interoperability.

Overall, the sectoral results support the RTIF's emphasis on cumulative integration: without skills, infrastructure gains remain underutilised, and without sustained usage, even advanced sectors can face uneven trajectories. The evidence also indicates that sectoral differences are shaped not only by firm characteristics but also by broader institutional and regulatory conditions. Policies, therefore, need to be sector-sensitive: creative industries may require support for frontier technologies, while industrial and service sectors benefit more from initiatives that prioritise workforce development and organisational readiness.

4.6.4. Regional Variations in Digital Technology Integration

Figure 31 illustrates the territorial disparities in digital access, skills, and usage across Italy's five NUTS 1 regions using the Gini coefficient, while Figure D4 in the appendix presents these same constructs through normalised indices, reflecting central tendencies. Together, these figures reveal how regions diverge not only in their levels of digital maturity but also in the distribution of digital resources and capabilities.

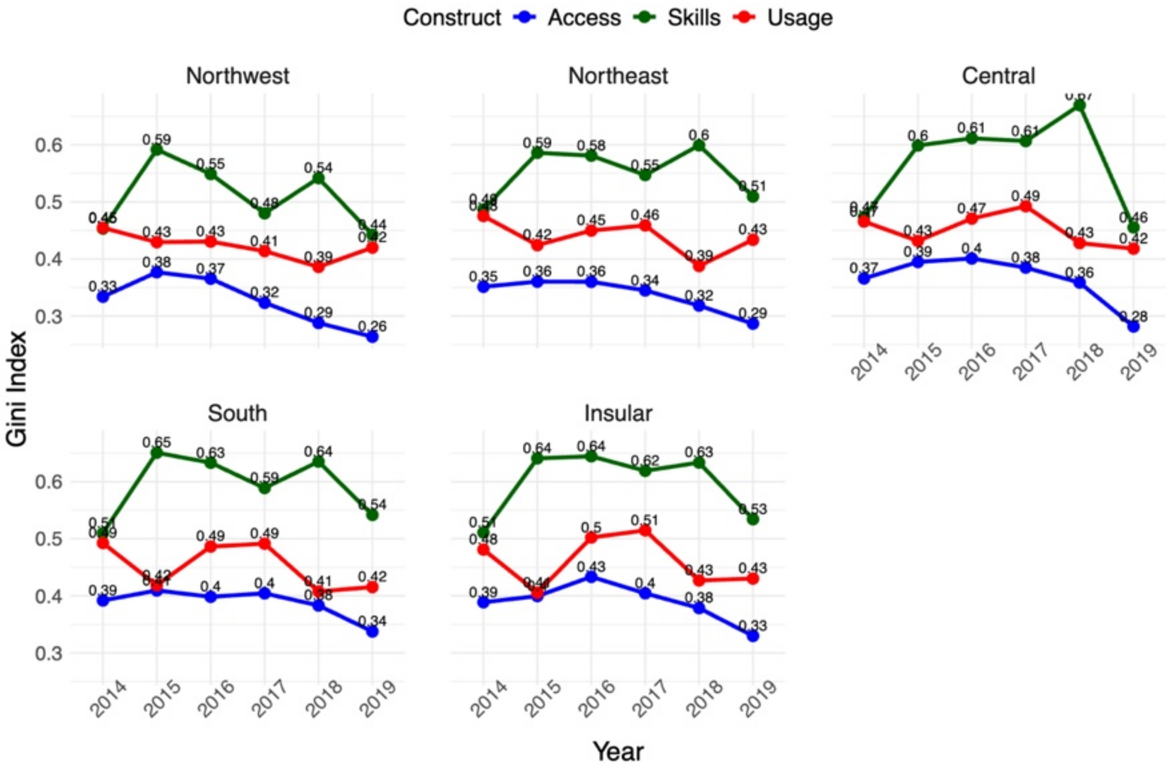

Figure 31:Yearly Trends in Digital Access, Skills, and Usage by NUTS 1 Regions (2014-2019). Source: Author's Elaboration.

The Northwest consistently shows stronger digital performance across all three dimensions, combining high maturity with relatively low inequality. The Gini index for access falls from 0.33 to 0.26, while the median rises from 0.39 to 0.60. Skills and usage follow similar trends, with moderate declines in inequality and steady growth in medians. This profile showcases a more inclusive digital ecosystem, aligning with the RTIF premise that cumulative integration benefits from robust infrastructure, a well-developed workforce, and high institutional quality. These results align with Benecchi et al. (2023), who identify the Northwest as Italy's top-performing region across rDESI pillars, and with Calvino et al. (2022), which portrays it as a benchmark for balanced digital development. They also correspond with Leydesdorff and Cucco's (2018) description of Lombardia and Emilia-Romagna as synergetic innovation subsystems. The relatively high Institutional Quality Index (IQI) scores (above 0.70) during this period provide additional context for why the Northwest was able to sustain both growth and inclusiveness in digitalisation.

The Northeast shows a similar access trajectory, with the Gini declining from 0.35 to 0.29 and the median rising from 0.31 to 0.49. Skill inequality, however, remains persistently high (~0.50), and the median skill level changes little. Despite this, usage improves, with more even distribution over time. This pattern suggests that firms may have relied on outsourcing or low-complexity solutions, consistent with Calvino et al.'s (2022) notion of selective adoption. Benedetti et al. (2025)also highlight that in some regions, digital maturity reflects selective adoption rather than integrated capabilities. EU-wide measures such as the *eIDAS Regulation* supported secure digital transactions during this period, providing a framework that may have facilitated usage despite limited skill development.

The Central region exhibits convergence in access, with the Gini coefficient dropping from 0.37 to 0.28 and the median increasing from 0.31 to 0.57. However, skills remain uneven, with inequality still above 0.45, and the median, although improving, is lagging. Usage rises modestly but does not close the gap. The results here are consistent with that view, suggesting that infrastructure provision alone does not translate into digital performance without stronger internal capabilities. Traversa and Ivaldi (2024) also point to weaknesses in digital public services, which may have constrained broader readiness. Although measures such as the *Credito d'imposta Formazione 4.0* were available nationally, their uptake appears to have been uneven, coinciding with Central regions' only partial progress along the RTIF pathway.

In the **South**, the disconnect between access and effective integration is most visible. Median access rises from 0.21 to 0.37, and Gini falls modestly to 0.34, suggesting some progress in infrastructure. Yet skills remain deeply unequal (Gini reaching 0.54), and the median skill index stagnates around 0.13. Usage shows similarly flat outcomes. These findings are consistent with Benedetti et al.'s (2025) characterisation of Southern firms as digitally deprived but engaged in selective integration, often adopting only basic tools such as social media or simple e-commerce. Failli et al. (2024) likewise find limited digital skills among individuals in the South. Persistent structural constraints (Szeles & Simionescu, 2020) may help explain why improvements in access did not coincide with stronger skill or usage outcomes. EU and national initiatives, particularly the *PON Imprese e Competitività (ERDF)*, specifically targeted Southern Italy with place-based investments. The continuing inequalities observed during and after its implementation suggest that broader institutional conditions, such as low IQI scores (below 0.35), limited the extent to which these programmes translated into more balanced digital integration.

The Insular regions follow a similar pattern to the South. Access improves steadily, with the median rising from 0.22 to 0.38 and a visible reduction in inequality, as the Gini coefficient for access falls to 0.34 by 2019. However, skills remain stagnant, with Gini values consistently above 0.50 and flat median levels across the period, reflecting persistent challenges in workforce development and digital capability building. Despite this, usage inequality remains relatively stable, hovering around 0.43, comparable to regions with significantly stronger institutional support and skill bases. This suggests a form of *low-threshold convergence*, in which firms across the region adopt basic digital tools to a similar degree, but stop short of more transformative uses. Such convergence likely reflects a narrow usage scope, focused on cost-effective solutions like social media marketing or basic online sales, as observed by Benedetti et al. (2025). Traversa and Ivaldi (2024) similarly find that the Islands consistently rank low in e-government development and digital public service availability, pointing to systemic constraints on institutional capacity and digital demand.

The gradual access improvements observed are consistent with infrastructure investments from policies like the *Piano BUL* (Banda Ultra Larga), which specifically targeted broadband expansion in lagging regions such as Sardinia and Sicily. Yet, the results underscore that *better infrastructure alone does not automatically translate into more advanced usage*, particularly in regions where institutional coordination, human capital, and digital leadership remain weak. These findings reaffirm the RTIF's emphasis on cumulative dependencies across constructs—access is necessary but not sufficient when skills and strategic integration capacity are lacking.

The regional analysis highlights the cumulative and path-dependent nature of digital integration in Italy, which is consistent with the RTIF framework. In the Northwest and Northeast, simultaneous progress in access, skills, and usage aligns with high institutional quality, stronger innovation ecosystems, and more advanced productive structures (Fabiani et al., 2005). By contrast, the South and Insular regions exhibit modest improvements in access but remain constrained by persistent deficits in digital skills and institutional capacity. These asymmetries are not merely recent or cyclical; they reflect longstanding structural divides. As shown by Nifo & Vecchione (2014), weak institutional environments in the South reduce absorptive capacity and drive outflows of skilled labour, compounding internal limitations. Lasagni et al. (2015) similarly demonstrate that firm productivity is systematically higher in regions with stronger institutions. These findings align with the policy recommendations of Serafini et al.

(2025), Calvino et al. (2019), and Benecchi et al. (2023), who call for regionally tailored strategies that integrate infrastructure development, skill upgrading, and institutional strengthening. They also echo Leydesdorff and Cucco's (2020) suggestion that innovation and digital policies in Italy may need to be framed at a supra-regional level to address persistent structural imbalances.

4.7. Conclusions

This chapter analysed disparities in digital technology adoption across Italian enterprises through the lens of the RTIF, focusing on access, skills, and usage. The results confirm the framework's central proposition: digital transformation is cumulative, with access enabling skills development, and both serving as preconditions for meaningful and sustained usage.

Substantial progress has been made in reducing first-level digital divides, particularly in access to computing technologies and internet infrastructure, driven in part by targeted policy interventions such as iperammortamento and broadband investments. However, persistent gaps in digital skills and uneven usage outcomes highlight that addressing foundational infrastructure is necessary but not sufficient for achieving digital maturity.

The RTIF's conceptualisation of access, skills, and usage as interdependent constructs is validated across multiple dimensions. While improved access has paved the way for modest gains in usage, regional and sectoral inequalities in digital skills continue to hinder this progression. Disparities in usage often reflect deeper capability gaps, revealing how organisational readiness, workforce development, and institutional context condition firms' ability to integrate and scale digital technologies.

There are notable differences between sectors. The ICT and creative industries have fairly balanced profiles, with relatively equal access and skills, but their slight decline in usage suggests they're moving towards more advanced digital tools. In contrast, the manufacturing sector has improved access, but still struggles with skills development, which hinders deeper integration. The services sector has the most uneven profile, with high access not matched by equivalent skills or usage, especially among small to medium-sized enterprises.

Regional evidence reinforces this interpretation. The North demonstrates more synchronised progress across the three constructs, supported by higher institutional quality and stronger innovation ecosystems. Conversely, the South and Insular regions continue to exhibit structural weaknesses: while access has improved, skills and usage remain stagnant, shaped by lower institutional capacity, weak absorptive ecosystems, and selective adoption of basic tools. These findings align with the view that regional digital disparities are embedded in broader patterns of path dependence and institutional asymmetry.

Importantly, the balance of policy attention during the observed period has leaned more heavily toward improving access than addressing digital skills or advanced usage. Major initiatives, such as *Piano BUL* and *iperammortamento*, as well as EU co-funded programmes like *PON Imprese e Competitività,* played a pivotal role in expanding digital infrastructure and lowering barriers to technology acquisition. More targeted efforts, such as the *Credito d'imposta Formazione 4.0* and the *Voucher Innovation Manager,* aimed to strengthen digital skills and internal absorptive capacity; however, these initiatives remained comparatively limited in scale and scope. Given that skill development and organisational change are cumulative and long-term processes, it is plausible that the effects of these latter policies may only become more visible after the observed period. This suggests the importance of sustained and coordinated strategies that integrate infrastructure provision with ongoing support for digital capabilities across firm sizes and sectors. Future research should prioritise evaluating the effectiveness of this battery of policy interventions not only in terms of technology adoption, but also in how they influence broader patterns of industrial upgrading, productivity, and regional development within Italy's evolving digital ecosystem.

One crucial methodological consideration emerging from the robustness checks concerns the inclusion of firm size as an active variable in the construction of the digital divide indices. While the Skills and Usage indices remained largely stable regardless of whether size was included, the Access index proved more sensitive to this specification. Excluding firm size from the factor model tended to overestimate access, suggesting that the infrastructural advantages of larger firms become less visible when size is not explicitly considered. This finding highlights a broader issue: firm size is not merely an explanatory variable, but also a structural factor that influences access to digital infrastructure and capabilities. Smaller firms often face constrained access to infrastructure, connectivity, and digital tools, a core dimension of the digital divide. Therefore, omitting firm size from the construction of the index may result in a less accurate representation of disparities, potentially understating the extent of structural inequalities in digital access. Future research may explore further refinements, such as multi-level modelling or alternative weighting schemes, to disentangle the influence of firm size while preserving the interpretative power of the indices.

Looking ahead, Italy's digital transition will increasingly hinge on firms' ability to adopt technologies beyond the foundational layer. Tools such as cloud computing, AI, and data analytics are no longer optional, yet they are embedded in highly concentrated global markets. This concentration raises barriers not just in cost but also in technical compatibility, certification regimes, and access to talent. While open-source ecosystems offer an alternative, more flexible and potentially inclusive, they shift the burden to internal skills and organisational commitment. This underlines that digital inequality is not merely about technology diffusion, but about firms' capacity to absorb, adapt, and integrate.

These dynamics echo the logic of punctuated equilibrium: digital transitions are not smooth or evenly distributed, but marked by discontinuous shifts. Firms and regions lacking foundational readiness face a pre-adaptive disadvantage, unable to capitalise on new technological opportunities, and at risk of further marginalisation. This is particularly acute for Italian SMEs, which remain structurally constrained in terms of both human capital and access to scalable digital solutions. Without targeted support, they risk becoming passive users or dependent on vendor-driven ecosystems with limited strategic control.

Finally, intangible factors such as leadership, organisational culture, and informal networks remain underexplored yet likely play a significant role in shaping outcomes. The RTIF offers a robust foundation for understanding digital divides, but it must evolve to capture these emergent complexities. Sectoral variation, regional disparities, and technological dependencies all suggest that future research and policy must adopt more adaptive, context-sensitive approaches. By integrating foundational and advanced technology layers, balancing infrastructure with capacity-building, and recognising institutional embeddedness, Italy can pursue a more inclusive digital transformation, one that enables all firms, not just digital frontrunners, to participate in and shape the digital economy.

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Appendix A: Data Processing Overview

This appendix is linked to a GitHub repository that contains detailed reports with statistical information gathered during each stage of the research. Each appendix section provides comprehensive insights into various aspects of the data processing and analysis, including missing data treatment, summary statistics, and factor analysis results. Additionally, each section contains respective links to the related reports in the repository, ensuring transparency and accessibility of the methodologies and findings.

Handling Missing Data

Figure A1 depicts the patterns of missing data for the ICT usage in enterprises survey in 2014. This visualisation highlights the percentages of missing values. While examining the consistency of the selected variables in the ICT usage in enterprises survey across all six years (2014-2019), several challenges were encountered in the survey conducted by ISTAT.

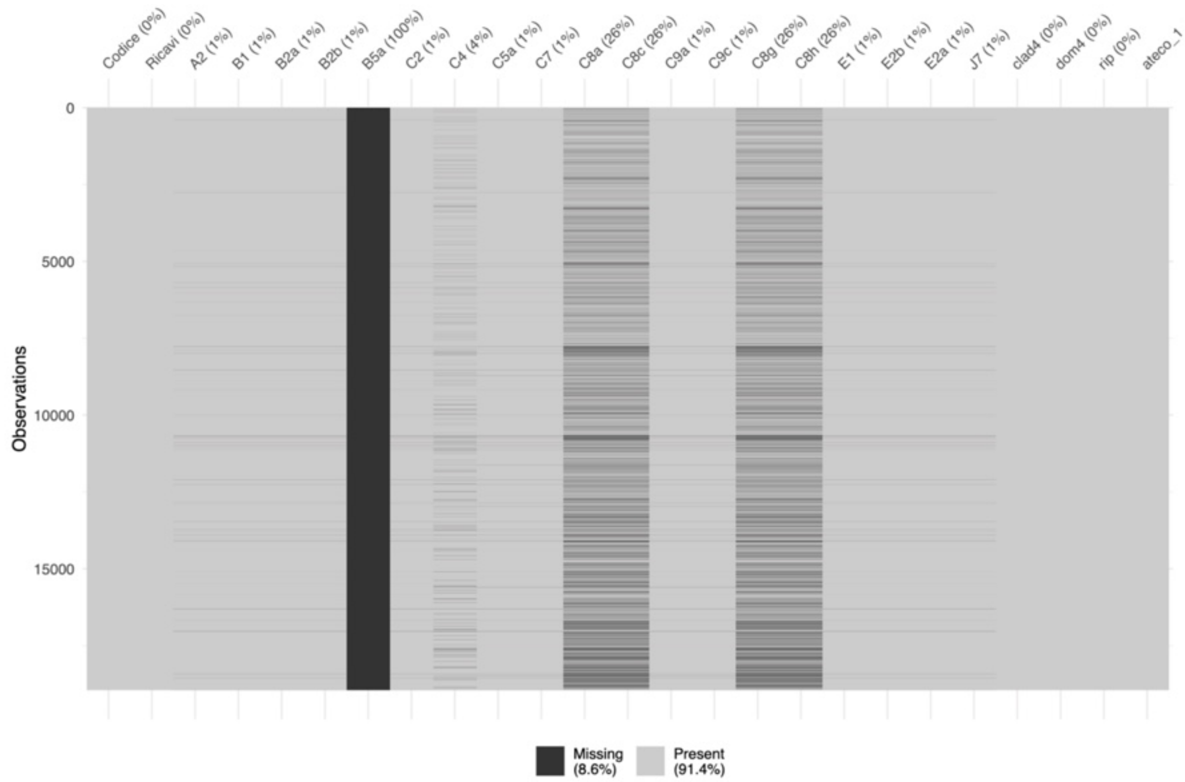


Figure A1: Missing Value Percentages for 2014.

Note: *For a detailed analysis of the imputation methodologies and associated statistical procedures, please refer to the report on **Missing data and imputation**.*

These challenges arose due to variable codification and measurement variations across different years. These differences indicate that the survey's methodology evolved over time, possibly in response to changes in technology or business practices. This leads to occasional alterations in how certain variables are defined or measured. To address this problem, imputations were performed to maintain the consistency of the selected observed variables while considering the integrity of the dataset.

Variables and Naming Conventions

Table A1 delineates the variable naming conventions utilised throughout this study to facilitate organised data analysis and straightforward interpretation. Each variable is categorised under a specific prefix that corresponds to different aspects of the integration of digital technologies, aiding in the streamlined analysis of data.

A (Access): Focuses on access to digital technologies, including both incentives (A1) and physical access (A2).

S (Skills): Captures various dimensions of digital skills within enterprises, spanning from general ICT training to specialised IT management.

U (Usage): Captures how digital technologies are implemented across different operational areas. This includes management applications such as enterprise resource planning (ERP) and customer relationship management (CRM) under UM, digital marketing and sales under UMK, and e-commerce and online transactions under UC.

Each prefix is followed by specific codes derived from the survey, enabling a systematic approach to data handling and analysis.

Code	Variable Name
A1_B2b	IT training courses for employees without specialist ICT skills
A2_A2	Percentage of employees using the computer out of the total employees
A2_C2	Percentage of employees using computers connected to the internet
A2_C4_high	Internet download speed high
A2_C4_low	Internet download speed low

A2_C5a	Enterprise provides mobile devices with mobile connection
S_B1	Employment of specialists in computer subjects
S_B2a	IT training courses for employees with specialist ICT skills
S_B5a1	Use of internal personnel for ICT infrastructure maintenance
S_B5b1	Use of internal personnel for office software support
S_B5c1	Use of internal personnel for enterprise software development
S_B5d1	Use of internal personnel for enterprise software support
S_B5e1	Use of internal personnel for web development
S_B5f1	Use of internal personnel for web development support
S_B5g1	Use of internal personnel for IT security management
UC_C8a	Possibility to place orders or reservations online e.g., online shopping cart
UC_J7	Web sales through intermediary websites or eCommerce sites, marketplaces or apps
UM_C8g	Announcement of vacancies or possibility to apply for employment online
UM_E1	Using ERP software
UM_E2a	Use analytical CRM software
UM_E2b	Use operational CRM software
UMK_C7	Use of Website
UMK_C8c	Access to product catalogs or price lists
UMK_C8h	Links or references to company profiles on social media
UMK_C9a	Social network
UMK_C9c	Social media and multimedia
size_rev_small	Firm size small
size_rev,medium	Firm size medium
size_rev_large	Firm size large

Table A1: List of Codes and Variables Names.

Summary Statistics and Distributions

The section presents comprehensive summary statistics for the 29 observed variables, providing detailed insights into their distribution and central tendencies. Additionally, it includes summary statistics for other contextual variables, such as sector and region, which are crucial for understanding the broader context of the data. This section also details the classification of firms by size based on revenue, as well as the naming and coding conventions employed throughout the research within the shared links.

Observed Variables

Table A2 provides a detailed statistical overview of the variable "IT training courses for employees without specialist ICT skills." Relating the variable type and the respective convention code. The table spans from 2014 to 2019, displaying the yearly proportion who participated in IT training courses. It also includes variance and standard deviation calculations to illustrate the distribution of responses, along with 95% confidence intervals that offer a statistical range within which the true proportion likely falls. This comprehensive summary aids in understanding the trends and variations in IT training participation among non-specialist ICT employees across the observed years.

Var name: IT training courses for employees without specialist ICT skills.						
Type: binary						
Code: A1_B2b						
Year	**Count**	**Prop_1s**	**Variance**	**std_dev**	**low_95_CI**	**up_95_CI**
2014	18832	0.14	0.12	0.35	0.14	0.15
2015	19322	0.17	0.14	0.37	0.16	0.17
2016	18892	0.17	0.14	0.38	0.17	0.18
2017	21195	0.18	0.15	0.38	0.18	0.19
2018	21825	0.23	0.18	0.42	0.22	0.23
2019	18383	0.27	0.20	0.44	0.26	0.27

Table A2: Annual Summary Statistics for IT Training Participation.

Note: *For further exploration of the statistics related to the other 28 variables used in this research, please visit the following report in the GitHub repository link: Summary statistics 29 variables.*

Contextual Variables

Table A3 provides a detailed breakdown of the proportion of firms categorised by industry sector from 2014 to 2019. The **ATECO code**, Italy's national adaptation of the NACE classification system used throughout the European Union, categorises firms based on their economic activity. This table lists 11 specific sectors included in the survey, such as manufacturing, wholesale retail, and media & ICT, among others. Also, it assigns these sectors into four broader macro classifications: Industrial, Commercial, Service, and Creative Industries and ICT. These groupings facilitate a clearer understanding and more straightforward reporting of results and trends within larger segments of the economy by allowing for more aggregated analysis. Each sector's yearly data illustrates the dynamic nature of industry participation over the six-year period, providing valuable insights into the shifting landscape of Italian business sectors.

ATECO code	Sector name	2014	2015	2016	2017	2018	2019	Macro Sector Classification
C	Manufacturing	22.94	24.24	25.03	25.04	21.3	21.84	Industrial
D_E	Energy & Water Treatment	7.27	7.13	6.72	6.95	5.9	7.00	Industrial
F	Construction	18.66	14.99	13.32	13.71	14.18	16.48	Industrial
G	Wholesale Retail	25.08	24.16	30.45	32.33	35.63	24.48	Commercial
H	Transport	4.25	3.87	3.61	3.74	3.91	4.01	Commercial
I	Accommodation	3.56	3.19	3.04	3.35	3.05	3.88	Service
J	Media & ICT	5.55	5.32	5.03	5.46	6.95	7.97	Service
L	Real Estate	1.3	1.19	1.11	1.06	1.15	1.21	Service
M	Professional, scientific and technical activities	4.78	5.2	4.23	2.84	2.68	4.72	Service
N	Rental & Travel	6.15	10.33	7.12	5.09	4.89	8.14	Creative Industries & ICT
S	Repair computers and communications	0.46	0.39	0.35	0.43	0.36	0.28	Creative Industries & ICT

Table A3: Annual Proportions of Firms by Sector and Macro-Sector Classification, 2014-2019.
Note: For more details on the 11 economic activity classifications, please visit the following report in the GitHub repository link: Summary Statistics by ATECO Classification.

Table A4 displays the percentage distribution of firms across four macro sectors from 2014 to 2019. It examines the trends in how Italian firms are spread across the industrial, commercial, service, and creative industries and ICT sectors. Over the six-year period, the industrial sector consistently holds the largest share. The commercial sector shows fluctuations, initially decreasing before experiencing a significant rise in 2018. The service sector exhibits variations, reaching a peak in 2015. While representing the smallest category, the creative industries and ICT sector have gradually increased, indicating a growing emphasis on this sector within the Italian economy.

Macro Sector	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Industrial	48.87	46.36	45.06	45.70	41.37	45.32
Commercial	26.38	25.34	31.55	33.39	36.78	25.69
Service	18.74	22.59	18.00	15.01	14.53	20.74
Creative Industries & ICT	6.01	5.71	5.38	5.89	7.31	8.25

Table A4 Proportion of Firms Across Macro Sectors, 2014-2019

Note: For further details relating to the macro sector classification, please visit the following report in the GitHub repository link: Summary Statistics Macro-Sector.

Table A5 provides a snapshot of the distribution of firms across Italy's five NUTS 1 regions from 2014 to 2019, capturing the proportion of firms in each region annually. The northwest and northeast consistently host a larger share of firms, with significant fluctuations over the years. In contrast, the central, south, and insular regions present more varied trends. This data underlines the dynamic economic landscape at the regional level, which may reflect varying economic policies, industry developments, or regional growth patterns. This table aids in understanding the geographical spread of firms within these major Italian regions over the six-year period, offering a macro-level insight into the regional business landscape.

Region	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Northwest	34.00	47.97	45.01	33.47	35.81	34.87
Northeast	29.38	26.53	28.00	26.41	26.64	28.59

Central	16.91	17.35	19.78	23.68	24.15	17.58
South	14.19	3.21	2.75	12.25	9.71	14.30
Insular	5.52	4.94	4.46	4.18	3.69	4.66

Table A5 Proportion of Firms Across Five Regions in Italy, 2014-2019

Note: Additional details on regional classification can be found in the "Summary Statistics at the Regional Level" report available in the GitHub repository.

Appendix B: Synthesis of Preliminary Tests and Implications for Factor Analysis

This appendix outlines the preliminary statistical analyses conducted to validate the research design and prepare data for factor analysis. It begins with ANOVA and Chi-Squared tests shown in Tables B1, B2, and B3 to verify the independence of yearly data, which is crucial for treating each year's dataset as separate and unlinked. Following this, correlograms in Figures B1, B2 and B3 assess correlations among 2014 variables to ensure they are appropriate for factor analysis. The appendix further details the use of Cronbach's Alpha in Tables B4, B5, and B6. Cronbach's Alpha measures the internal consistency of the variables for 2014. These procedures establish a solid statistical foundation, allowing for robust factor analysis of the investigated constructs. Detailed results for correlations and Cronbach alpha for subsequent years are available in the *"Factor Analysis Pre-processing"* report on the GitHub repository.

Testing Yearly Independence

This section presents the ANOVA and Chi-Squared tests conducted for the three primary constructs: Access, Skills, and Usage. These tests evaluate the assumption of independence across yearly data, which is essential for treating each dataset as unique and unconnected. Results across all three constructs consistently reject the null hypothesis, indicating significant differences in the data each year, which underscores the non-homogeneity of the samples over time.

Variable	Test	Test_Statistic	P_Value	Decision
A2_A2	ANOVA	498.408	0.000	Reject Null Hypothesis
A2_C2	ANOVA	458.831	0.000	Reject Null Hypothesis
A1_B2b	Chi-Squared Test	1266.019	0.000	Reject Null Hypothesis
A2_C5a	Chi-Squared Test	976.182	0.000	Reject Null Hypothesis
A2_C4_low	Chi-Squared Test	8350.129	0.000	Reject Null Hypothesis
A2_C4_high	Chi-Squared Test	8350.129	0.000	Reject Null Hypothesis
size_rev_small	Chi-Squared Test	390.418	0.000	Reject Null Hypothesis
size_rev_medium	Chi-Squared Test	138.519	0.000	Reject Null Hypothesis

size_rev_large	Chi-Squared Test	186.434	0.000	Reject Null Hypothesis

Table B1 Independence Tests for Access Variables Across 2014-2019.

Variable	Test	Test_Statistic	P_Value	Decision
S_B1	Chi-Squared Test	184.663	0.000	Reject Null Hypothesis
S_B2a	Chi-Squared Test	992.494	0.000	Reject Null Hypothesis
S_B5a1	Chi-Squared Test	59.539	0.000	Reject Null Hypothesis
S_B5b1	Chi-Squared Test	72.899	0.000	Reject Null Hypothesis
S_B5c1	Chi-Squared Test	53.649	0.000	Reject Null Hypothesis
S_B5d1	Chi-Squared Test	78.987	0.000	Reject Null Hypothesis
S_B5e1	Chi-Squared Test	40.258	0.000	Reject Null Hypothesis
S_B5f1	Chi-Squared Test	77.468	0.000	Reject Null Hypothesis
S_B5g1	Chi-Squared Test	190.341	0.000	Reject Null Hypothesis
size_rev_small	Chi-Squared Test	390.418	0.000	Reject Null Hypothesis
size_rev_medium	Chi-Squared Test	138.519	0.000	Reject Null Hypothesis
size_rev_large	Chi-Squared Test	186.434	0.000	Reject Null Hypothesis

Table B2 Independence Tests for Skills Variables Across 2014-2019

Variable	Test	Test_Statistic	P_Value	Decision
UMK_C7	Chi-Squared Test	698.477	0.000	Reject Null Hypothesis
UC_C8a	Chi-Squared Test	277.000	0.000	Reject Null Hypothesis
UMK_C8c	Chi-Squared Test	154.772	0.000	Reject Null Hypothesis
UM_C8g	Chi-Squared Test	237.944	0.000	Reject Null Hypothesis
UMK_C8h	Chi-Squared Test	3141.118	0.000	Reject Null Hypothesis
UM_E1	Chi-Squared Test	125.392	0.000	Reject Null Hypothesis
UM_E2b	Chi-Squared Test	1202.339	0.000	Reject Null Hypothesis
UM_E2a	Chi-Squared Test	995.805	0.000	Reject Null Hypothesis
UC_J7	Chi-Squared Test	18160.321	0.000	Reject Null Hypothesis

UMK_C10a	Chi-Squared Test	2553.694	0.000	Reject Null Hypothesis
UMK_C10c	Chi-Squared Test	1433.133	0.000	Reject Null Hypothesis
size_rev_small	Chi-Squared Test	390.418	0.000	Reject Null Hypothesis
size_rev_medium	Chi-Squared Test	138.519	0.000	Reject Null Hypothesis
size_rev_large	Chi-Squared Test	186.434	0.000	Reject Null Hypothesis

Table B3 Independence Tests for Usage Variables Across 2014-2019

Analysing Variable Correlations

Correlation analysis is critical as it helps to identify and confirm the relationships between variables within each construct, ensuring that they are suitably correlated for factor analysis. Correlograms, such as those in Figures B1, B2, and B3, visually display these correlations, helping to discern whether the underlying variables within each construct share enough common variance to justify factor extraction.

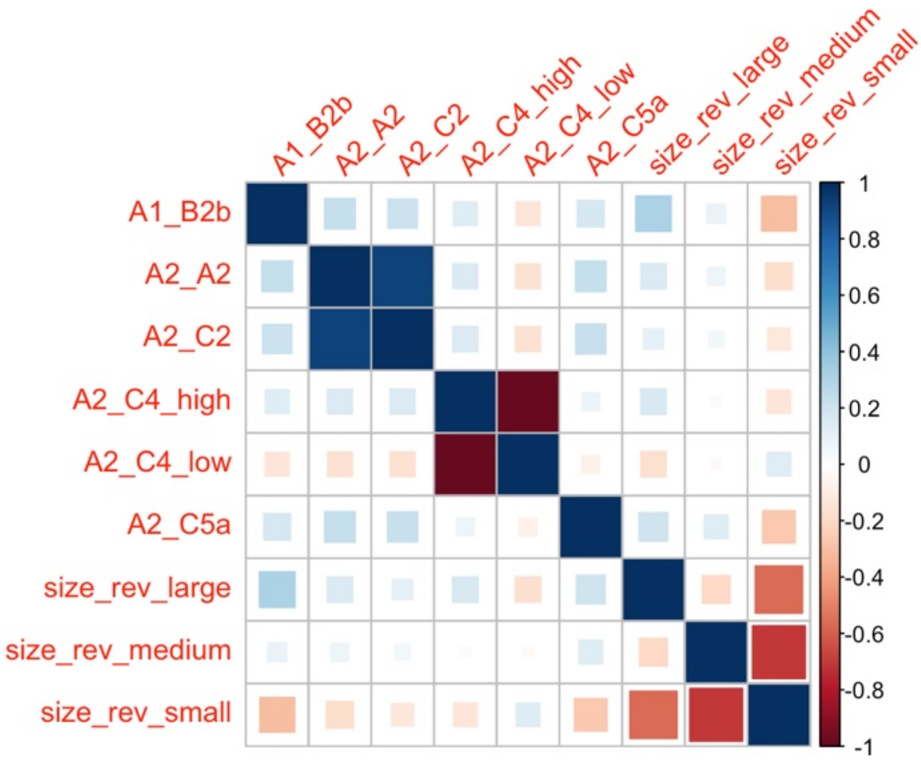


Figure B1: Correlogram for Access Variables in 2014.

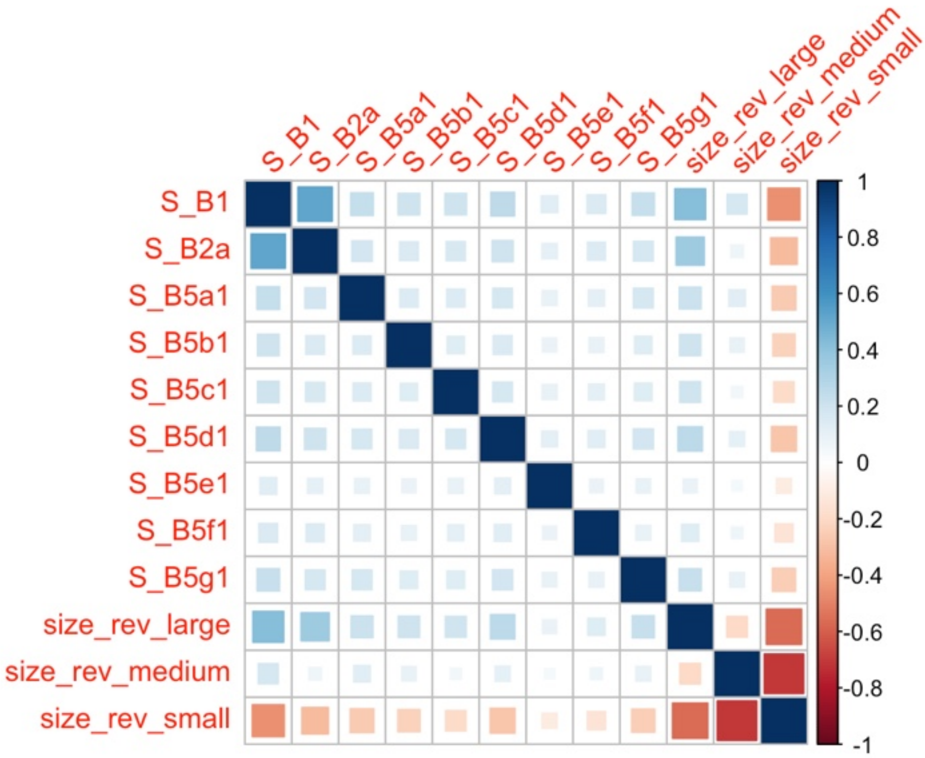


Figure B2: Correlogram for Skills Variables in 2014.

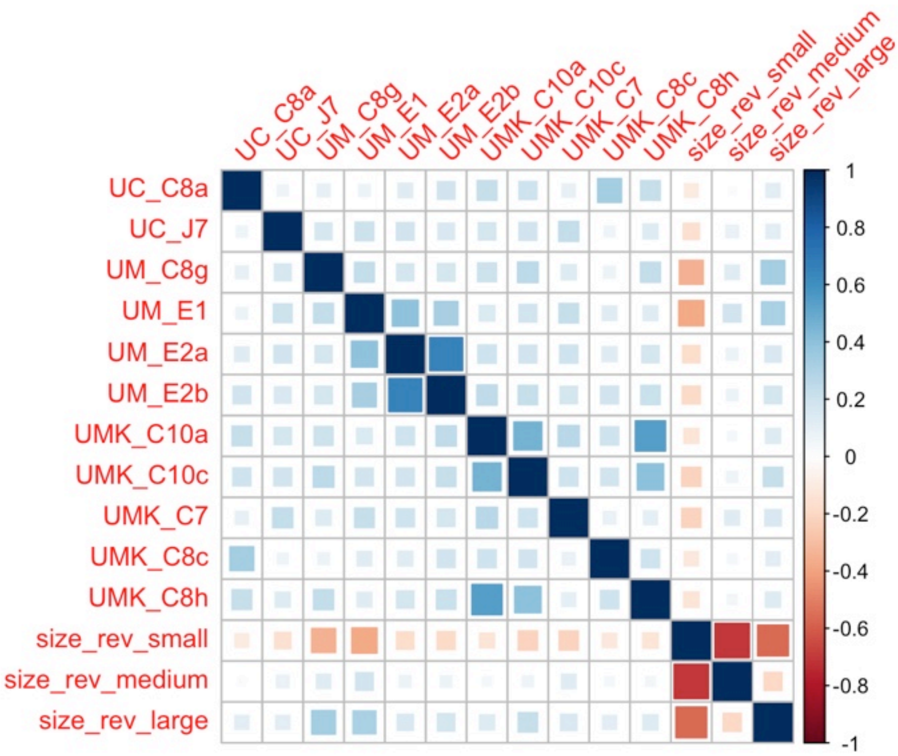


Figure B3: Correlogram for Usage Variables in 2014.

For correlograms of the subsequent years, please visit the *"Factor Analysis Pre-processing"* report on the GitHub repository.

Assessing Construct Reliability

This section discusses the reliability of constructs through Cronbach's Alpha, which measures the internal consistency of the variables. The raw alpha metric is evaluated against established thresholds to determine reliability; values above 0.70 are generally considered acceptable, indicating good internal consistency among the variables within each construct.

raw_alpha	std.alpha	G6(smc)	average_r	S/N	Var_type
0.963	0.963	0.929	0.929	25.974	Continuous
0.667	-1.751	-1.422	-0.100	-0.637	Binary
0.710	-0.045	0.192	-0.005	-0.043	Combined

Table B4 Reliability Test Cronbach Alpha for Access in 2014

raw_alpha	std.alpha	G6(smc)	average_r	S/N	Var_type
0.726	0.496	0.515	0.076	0.984	Binary

Table B5 Reliability Test Cronbach Alpha for Skills in 2014.

raw_alpha	std.alpha	G6(smc)	average_r	S/N	Var_type
0.767	0.648	0.688	0.116	1.842	Binary

Table B6 Reliability Test Cronbach Alpha for Usage in 2014

For further explorations of reliability tests in subsequent years, please visit the *"Factor Analysis Pre-processing"* report on the GitHub repository

Inclusion of Weights in FAMD and MCA

In this study, weights were incorporated into the FAMD (Factorial Analysis for Mixed Data) and MCA (Multiple Correspondence Analysis) functions to account for the varying sample sizes across different groups. This weighting scheme ensures that the analysis accurately reflects the distribution and importance of each subgroup within the dataset. The weights were applied to balance the influence of different groups, such as:

- Years: Accounting for variations in sample sizes across different periods.

- Regions: Ensuring representation from diverse geographical areas.

- Sectors: Reflecting the distribution of firms across various industry sectors.

- Revenue Levels: Balancing firms with different revenue scales.

- Firm Sizes: Adjusting for representing small, medium, and large firms.

By applying these weights, the analysis more accurately represents the population structure, leading to more reliable and generalisable results. The weighting helps mitigate biases that could arise from over- or under-represented groups, thereby enhancing the validity of the factor analysis.

Calculation Process

1. Group Calculation: The dataset was divided into subgroups based on year, region, revenue levels, sectors, and firm sizes.

2. Count and Proportion:

   - The number of observations in each subgroup was counted.

   - The proportion of each subgroup relative to the total number of observations was calculated.

3. Initial Weight Assignment: Each subgroup was assigned a weight based on the inverse of its proportion, giving more weight to smaller subgroups to balance their influence.

4. Normalisation:

   - The weights were normalised within each year so that they sum to the total number of observations in that year.

Appendix C: Factor Analysis Metrics and Figures

This appendix presents the outcomes of the factor analysis conducted in 2014, focusing on three main constructs: Access, Skills, and Usage. Included in this section are the eigenvalues, scree plots, and the contributions of each variable to the identified dimensions. This analysis provides a detailed examination of how different ICT-related variables cluster together and influence the overarching constructs within the dataset.

For a comprehensive view of the factor analysis results from 2015 to 2019, please refer to the *"Composite Indices Results"* report available on the GitHub repository. This report extends the analysis presented here by detailing the factor analysis outcomes for each subsequent year, offering a broader perspective on the evolution of the constructs over time.

Access

Table C1 presents the eigenvalues for the "Access" construct derived using the FAMD function from the "FactoMineR" and "factoextra" packages in R for the year 2014. This table details the eigenvalues for seven retained dimensions, alongside the percentage of variance explained by each dimension and their cumulative contributions. The first dimension accounts for approximately 31.23% of the variance, with each subsequent dimension contributing progressively less, culminating in a total explained variance of 100% by the seventh dimension. This breakdown is crucial for determining the significant dimensions necessary to interpret the structure of Access in the dataset effectively.

Dimensions	Eigenvalue	Variance Percent	Cumulative Variance Percent
1 Dim	2.811	31.237	31.237
2 Dim	1.754	19.490	50.726
3 Dim	1.595	17.726	68.452
4 Dim	1.216	13.511	81.963
5 Dim	0.826	9.174	91.137
6 Dim	0.729	8.094	99.232
7 Dim	0.069	0.768	100

Table C1 Eigenvalues of Access in 2014.

Figure C1 displays the scree plot from the factor analysis of the Access construct for 2014. It illustrates the variance explained by each of the seven dimensions analysed. The plot demonstrates the rapid decrease in the percentage of variance each dimension accounts for, with the first dimension alone explaining 31.2% of the total variance. This indicates its substantial influence on the Access construct. Following this, the contribution of each successive dimension diminishes significantly, with the seventh dimension adding just 0.8%. This scree plot is instrumental in determining the optimal number of dimensions to retain, as it clearly shows the point at which additional dimensions cease to provide substantial explanatory value.

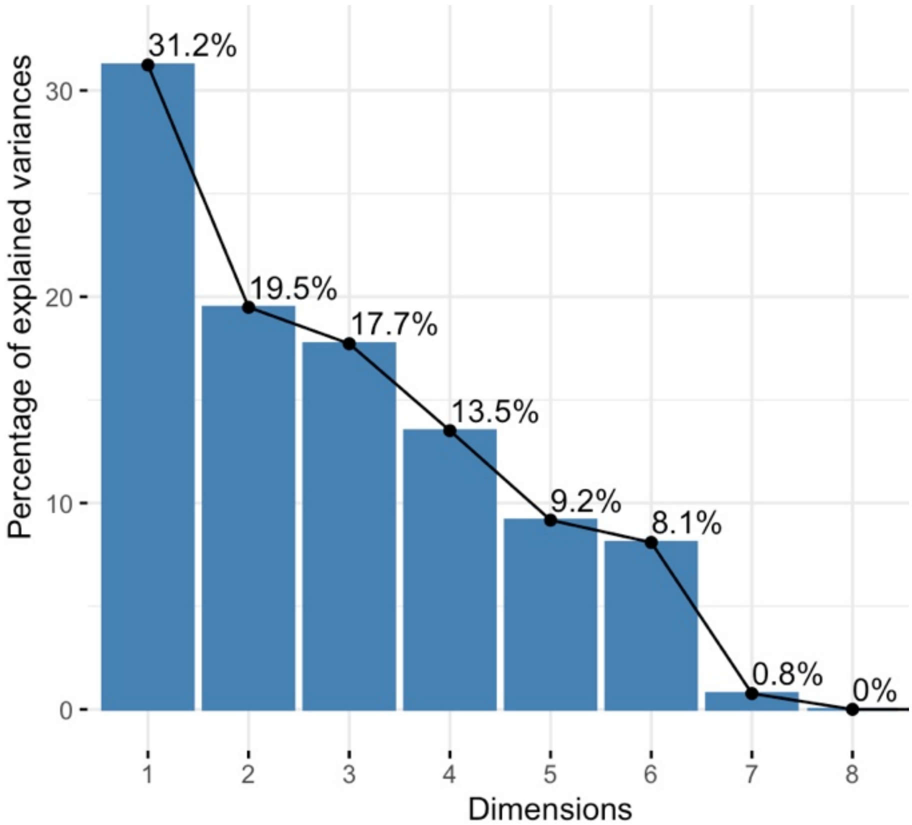


Figure C1: Distribution of Explained Variance Across Dimensions for Access in 2014.

Figure C2 visually represents the contributions of various variables to the first dimension of the Access construct from the 2014 factor analysis. Each bar signifies the percentage of explained variance contributed by a specific variable within this dimension. Notable contributors include "A2_A2" and "A2_C2," representing the percentage of personnel using computers. The variables "A2_C4_low" and "A2_C4_high," which denote internet speeds, along with "size_rev_small" indicating small enterprise presence, also play significant roles. The dashed red line marks a significance threshold, emphasising variables that provide substantial explanatory power to the Access construct, thus highlighting their importance in the analytical model. This graph aids in discerning which variables are most influential in capturing the essence of Access within enterprises.

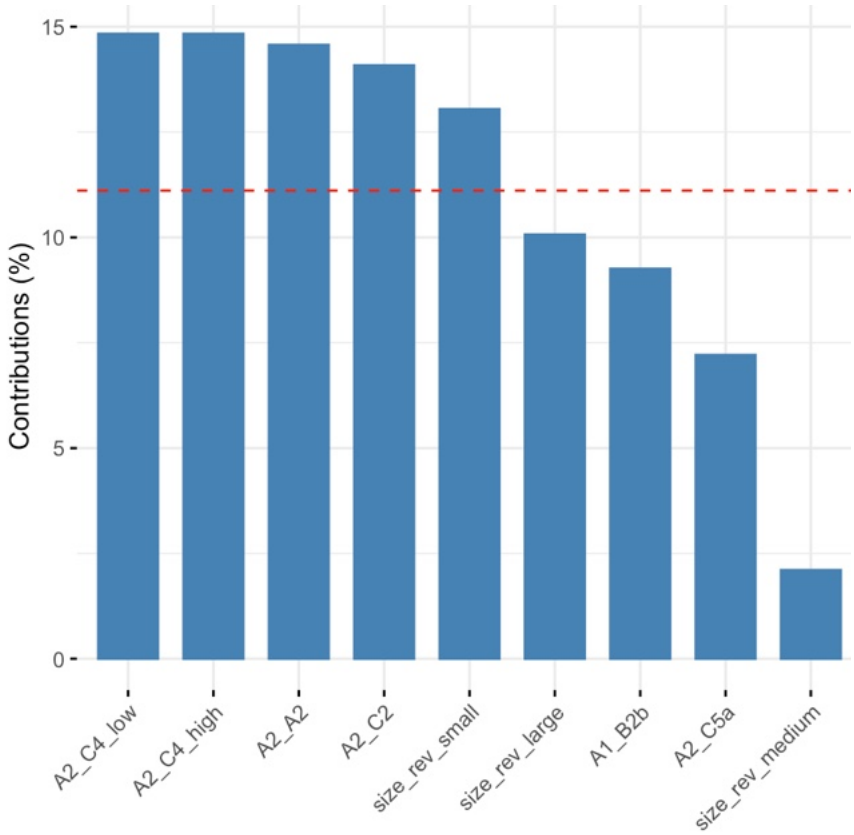


Figure C2: Contributions of Variables to the First Dimension of Access in 2014.

Figure C3 depicts the contributions of different variables to the second dimension of the Access construct for 2014. This graph underscores the variables that significantly influence this dimension, providing a clearer understanding of the underlying facets of Access. Notably, "A2_C4_low" and "A2_C4_high," which represent the lower and higher internet download speeds, respectively, are the predominant contributors, each explaining over 30% of the variance. This indicates that internet speed variations are critical in shaping this dimension of Access. The variables "size_rev_medium" and "size_rev_small," which reflect the scale of enterprises, also show meaningful contributions, suggesting the impact of enterprise size on access to digital technologies. The red dashed line acts as a significance threshold, highlighting that variables above this line are more impactful in defining the dimension. This analysis is vital for pinpointing which factors are crucial in understanding the secondary aspects of digital access within firms.

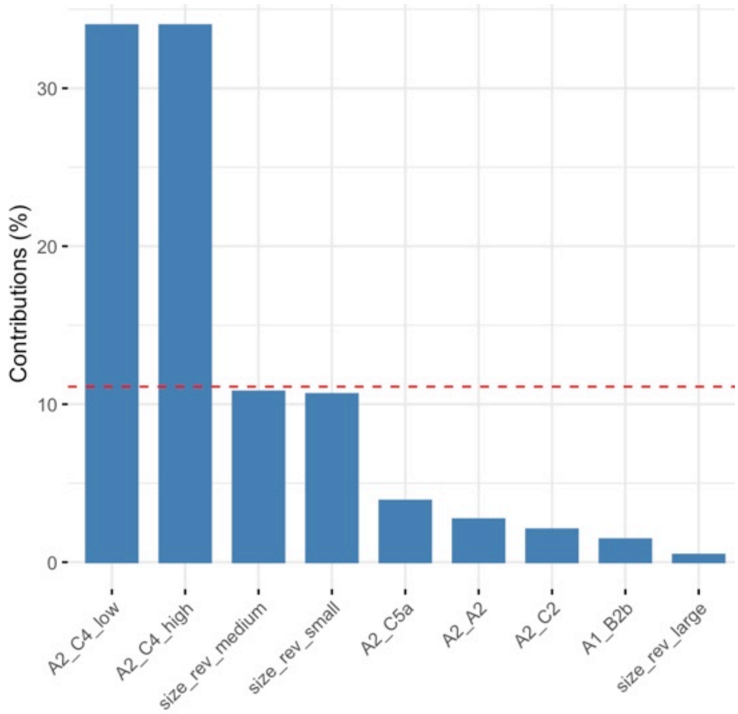


Figure C3: Contributions of Variables to the Second Dimension of Access in 2014.

Figure C4 illustrates the percentage contributions of different variables to the third dimension of the Access construct, as determined by the 2014 factor analysis.

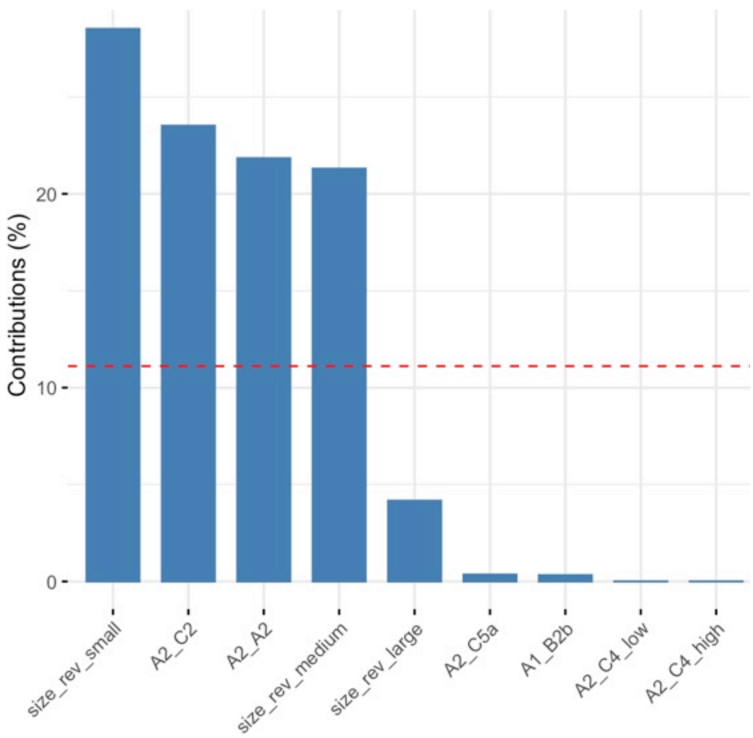


Figure C4: Contributions of Variables to the Third Dimension of Access in 2014.

The analysis identifies the most substantial contributors to this dimension, namely "size_rev_small," which signifies small firms. Additionally, the contributions from "A2_C2" and "A2_A2" are noteworthy; these variables pertain to the physical presence of computers and their connectivity to the internet. Collectively, these variables are essential in shaping the third dimension of the Access construct, highlighting the critical role that small firms and their digital infrastructure play in the broader context of access. Moreover, a red dashed line is included in the figure to indicate a threshold, above which the variables are deemed to have a more significant impact on defining this dimension of access.

Figure C5 shows the variable contributions to the fourth dimension of the Access construct in 2014, highlighting the impact of enterprise size. "Size_rev_large" and "size_rev_medium" are the most influential, indicating the significant role of larger enterprises in shaping this dimension. This suggests that in larger firms, aspects like employee training and scale of operations are pivotal in defining their digital access capabilities.

Variables related to IT training for employees without specialist ICT skills and internet connectivity are less influential, suggesting a lesser focus on basic digital infrastructure in this dimension. The red dashed line marks a significance threshold, emphasising the critical contributions of enterprise size and employee training in understanding digital access dynamics within larger enterprises.

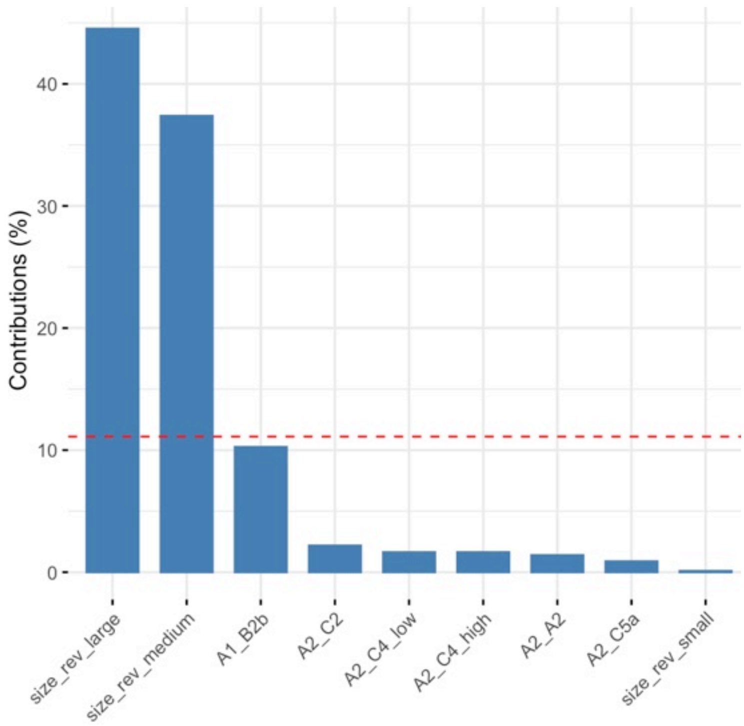


Figure C5: Contributions of Variables to the Fourth Dimension of Access in 2014.

Skills

Table C2 and Figure C6 collectively provide a detailed overview of the explained variance across the dimensions for the Skills construct in 2014. Table C2 outlines the eigenvalues, the percentage of variance explained by each dimension, and the cumulative variance percentages, while Figure C6 complements this information visually, showing both the percentage of variance explained by each dimension (as bars) and the cumulative variance (as a line plot).

The first dimension explains 26.72% of the variance, representing the most significant contribution to the Skills construct. This is followed by the second dimension with 11.60% and the third dimension with 9.60%. Together, these three dimensions account for nearly half (47.93%) of the total variance. Beyond the third dimension, the percentage of variance explained by each additional dimension diminishes progressively. For instance, the fourth to the sixth dimensions each explain between 7% and 8% of the variance, while the contributions of the remaining dimensions are smaller, gradually decreasing to 3.65% for the eleventh dimension.

Dimensions	Eigenvalue	Variance Percent	Cumulative Variance Percent
1 Dim	0.267	26.720	26.720
2 Dim	0.116	11.603	38.323
3 Dim	0.096	9.603	47.926
4 Dim	0.077	7.663	55.589
5 Dim	0.073	7.314	62.903
6 Dim	0.072	7.232	70.135
7 Dim	0.069	6.910	77.045
8 Dim	0.067	6.673	83.717
9 Dim	0.065	6.515	90.232
10 Dim	0.061	6.116	96.349
11 Dim	0.037	3.651	100

Table C2 Eigenvalues and Variance Explained for the Skills Construct in 2014.

The cumulative variance, displayed in both Table C2 and the line plot in Figure C6, demonstrates that the first six dimensions together account for 70.14% of the total variance. By the tenth dimension, the cumulative variance reaches 96.35%, indicating that the majority of the variance is captured within the first ten dimensions. The steep decline in variance contribution after the initial dimensions, as shown in Figure C6, emphasises the diminishing explanatory power of additional dimensions.

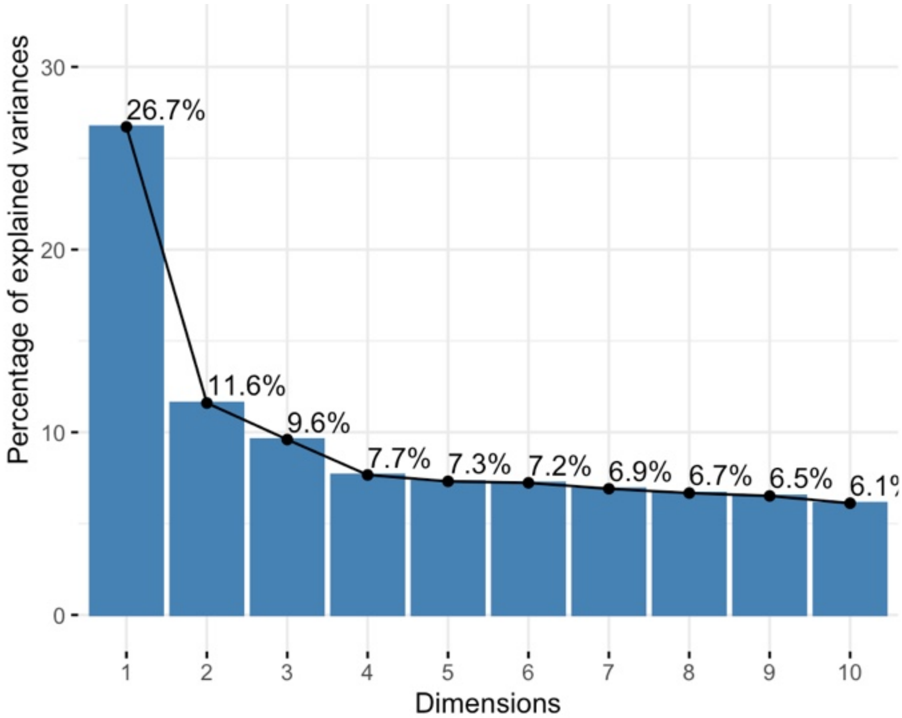
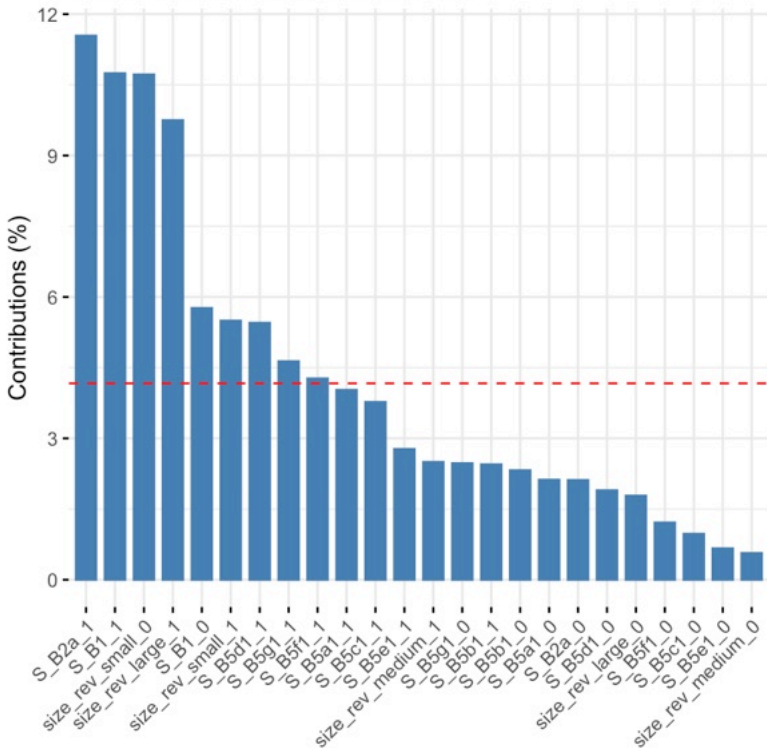


Figure C6: Distribution of Explained Variance Across Dimensions for Skills in 2014.

Figure C7 illustrates the contributions of specific categories within variables to the first dimension of the Skills construct for 2014, derived from Multiple Correspondence Analysis (MCA), tailored for categorical data.

The leading contributors are **'S_B2a_1' - IT Training Courses for Employees with Specialist ICT Skills (Category 1): This variable stands out as a principal contributor, indicating that offering specialised ICT training is pivotal in defining the skills dimension. It reflects an emphasis on enhancing advanced technical competencies within the workforce, a crucial factor in leveraging ICT for competitive advantage. 'S_B1_1' - Employment of Specialists in Computer Subjects (Category 1): The presence of specialists in computer subjects as a significant factor underscores the importance of skilled human resources in ICT. This variable suggests that the depth of expertise in IT departments strongly influences the organisation's overall digital capabilities. 'Size_rev_small_0' - Small Enterprise (Category 0): This indicates that being a small enterprise does not heavily contribute to this dimension, suggesting that other factors**

might be more defining for skills development in smaller settings. This could reflect resource constraints or different priorities in smaller enterprises compared to their larger counterparts. 'Size_rev_large_1' - Large Enterprise (Category 1): Conversely, large enterprises contribute significantly, highlighting that sizeable organisations likely have more structured training programs and specialised ICT roles. This contribution points to the scale at which larger enterprises can implement and manage sophisticated ICT

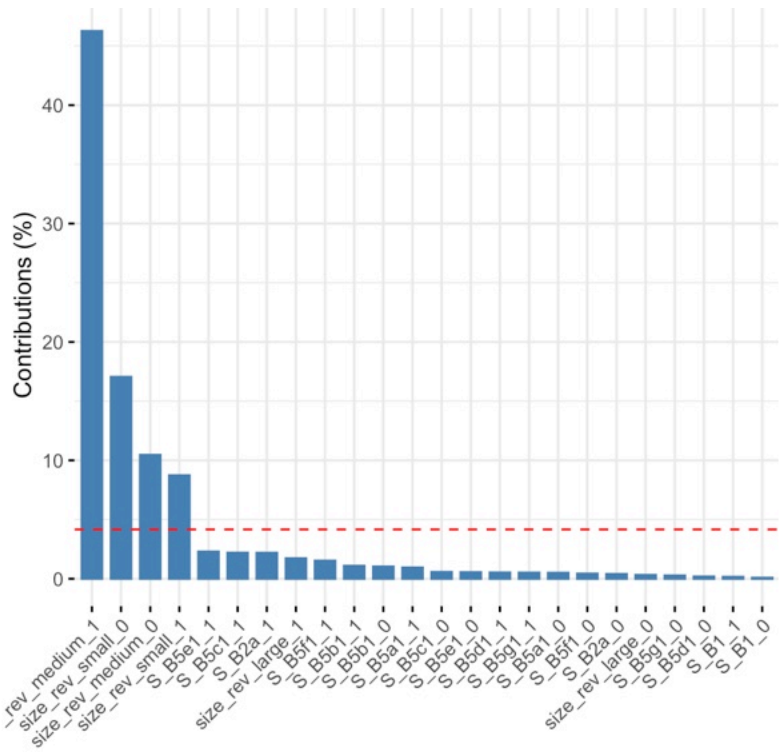


strategies, influencing the skills available within the company.

Figure C7: Contributions of Variables to the First Dimension of Skills in 2014.

Figure C8 provides an in-depth analysis of the variable contributions to the second dimension of the Skills construct for the year 2014, highlighting the significant influence of enterprise size on this dimension. Within the illustration, the "medium" and "small" enterprise categories are represented alongside their respective presence and absence indicators, specifically 'size_rev_medium_1', 'size_rev_medium_0', 'size_rev_small_1', and 'size_rev_small_0'. This representation reveals a nuanced impact these sizes have on the skills dimension, suggesting that specific features associated with, or lacking in, medium and small enterprises play a crucial role in shaping the overall skills framework.

Additionally, the simultaneous display of both positive and negative contributions for each size category emphasises the intricate and multifaceted relationship between enterprise size and the development and deployment of skills. This complexity necessitates the implementation of tailored strategies that take into account the diverse characteristics and needs specific to different types of enterprises. By understanding these nuances, stakeholders can better address the skills challenges faced by organisations of varying sizes, leading to more effective skills



development initiatives.

Figure C8: Contributions of Variables to the Second Dimension of Skills in 2014.

Figure C9 showcases the variable contributions to the third dimension of the Skills construct in 2014. This dimension is notably influenced by factors related to enterprise size and specific technological functionalities within the firms. The most prominent contributors include 'size_rev_large_1', indicating significant effects from larger enterprises, and 'S_B51_1', which pertains to the utilisation of internal personnel for web development. Another key contributor is 'S_B5c1_1', reflecting the employment of internal personnel for enterprise software development. These variables collectively highlight a dimension where enterprise scale and advanced IT functionalities interplay, suggesting that larger firms may have more structured internal IT services that impact their overall skills profile. This alignment of variables underlines the specialised IT development capacities that larger enterprises likely possess, shaping the skills landscape in a distinctive manner.

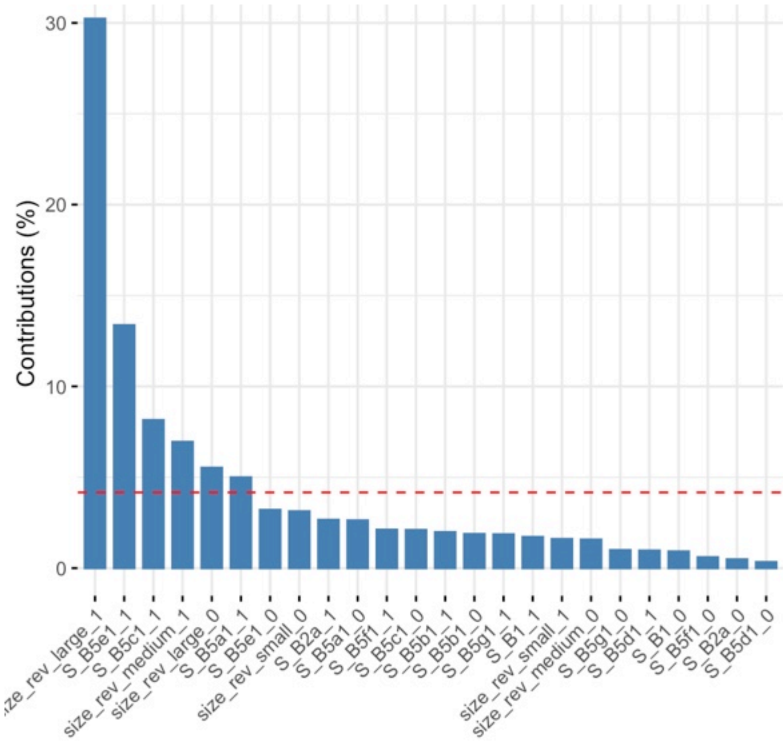


Figure C9: Contributions of Variables to the Third Dimension of Skills in 2014.

Figure C10 visualises the contributions of individual variables to the fourth dimension of the Skills construct from the factor analysis conducted for 2014. This dimension is heavily influenced by variables associated with specialised internal IT support roles within firms. The most substantial contributions come from 'S_B5f1_1', indicating the importance of personnel for web development support, followed by 'S_B5d1_1' and 'S_B5c1_1', which pertain to support for enterprise software and enterprise software development, respectively. These contributions underscore a dimension where internal IT support plays a critical role, reflecting the deeper layers of IT infrastructure support that enhance the overall skills framework within enterprises. The plot delineates how these specialised support roles contribute significantly to shaping the skills landscape, highlighted by their prominence above the significance threshold marked by the red dashed line.

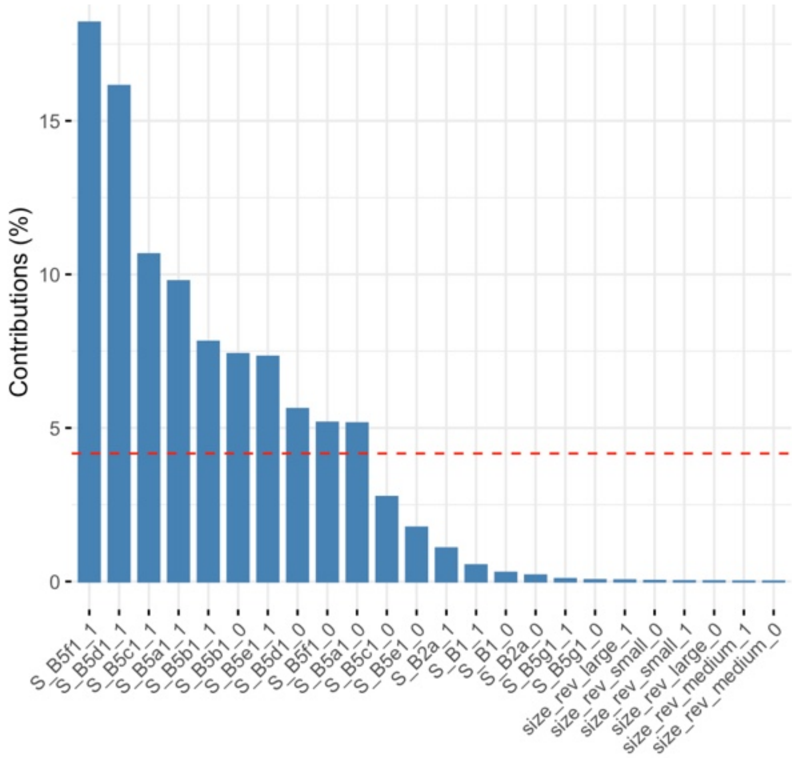


*Figure C10: Contributions of Variables to the Fourth Dimension of Skills in 2014***.**

USAGE

Table C3 and Figure C11 provide a comprehensive analysis of the explained variance across dimensions for the Usage construct in 2014, derived through Multiple Correspondence Analysis (MCA) due to the categorical nature of the variables. Table C3 presents the eigenvalues, the percentage of variance explained by each dimension, and the cumulative variance percentages, while Figure C11 visually illustrates these contributions through bar plots for individual dimensions and a line plot for cumulative variance.

The first dimension is the most significant, with an eigenvalue of 0.252, explaining 25.22% of the variance in the Usage construct. The second and third dimensions explain 12.88% and 9.85%, respectively, bringing the cumulative variance to 47.96% within the first three dimensions. This highlights the primary contributions of these dimensions to the construct. As shown in Table C3, the percentage of variance explained decreases progressively with each subsequent dimension, with dimensions four and five contributing 8.75% and 8.15%, respectively.

By the sixth dimension, the cumulative variance reaches 71.52%, indicating that the majority of the variance is captured within the first six dimensions. Additional dimensions, such as the seventh and eighth, contribute less than 6%, with diminishing returns as the number of dimensions increases. The cumulative variance approaches 100% at the thirteenth dimension, as shown in both Table C3 and the cumulative variance line in Figure C11.

Dimensions	**Eigenvalue**	**Variance Percent**	**Cumulative Variance Percent**
1 Dim	0.252	25.223	25.223
2 Dim	0.129	12.882	38.105
3 Dim	0.099	9.852	47.957
4 Dim	0.087	8.749	56.707
5 Dim	0.081	8.146	64.853
6 Dim	0.067	6.664	71.516
7 Dim	0.056	5.639	77.156
8 Dim	0.049	4.866	82.022
9 Dim	0.046	4.576	86.598
10 Dim	0.043	4.267	90.865
11 Dim	0.040	3.986	94.851
12 Dim	0.029	2.854	97.705
13 Dim	0.023	2.295	100

Table C3 Eigenvalues and Variance Explained for the Usage Construct in 2014.

Figure C11 visually emphasises the steep decline in explained variance after the first dimension, with the line plot flattening significantly after the sixth dimension. This pattern highlights the diminishing explanatory value of subsequent dimensions and supports focusing on the first six dimensions for further analysis.

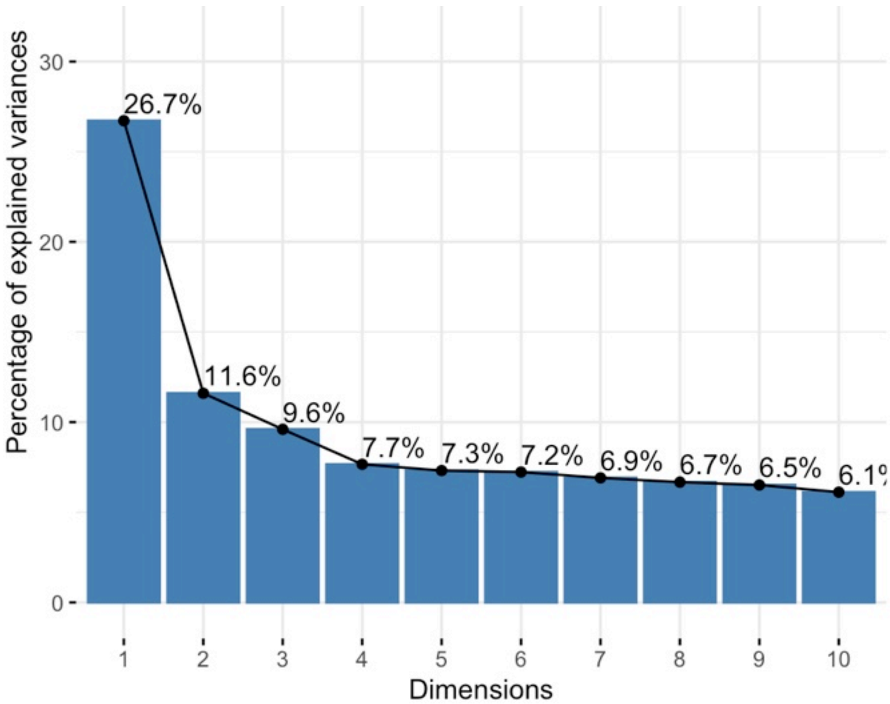


Figure C11: Distribution of Explained Variance Across Dimensions for Usage in 2014.

Figure C12 highlights the contributions of individual variables to the first dimension of the Usage construct in the 2014 data. The chart demonstrates the variability in contributions, with the most influential variables being 'UMK_C10c_1' which pertains to the use of social media and multimedia, 'UM_E2b_1' which involves the use of operational CRM software, 'UMK_C10a_1' related to social networking activities, and 'size_rev_small_0' indicating small enterprise size. These variables significantly shape the framework of digital usage within businesses, highlighting critical areas such as social media engagement and customer relationship management as dominant aspects in this dimension. The red dashed line denotes a significance threshold, suggesting that variables above this line are particularly impactful in defining the Usage construct in the dataset.

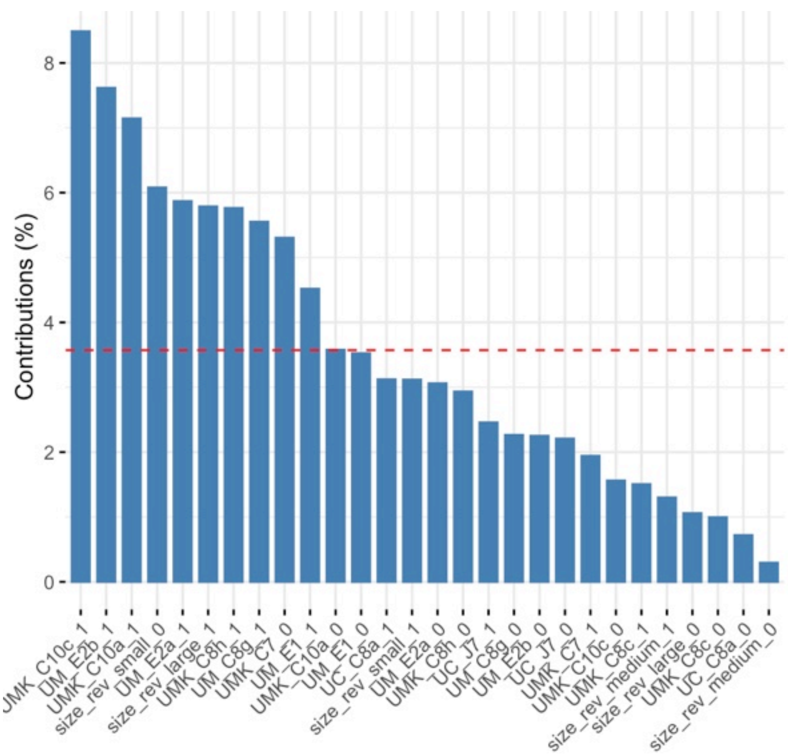


Figure C12: Contributions of Variables to the First Dimension of Usage in 2014.

Figure C13 showcases the distribution of contributions across various variables to the second dimension of the Usage construct for the year 2014. This dimension significantly highlights the impact of enterprise size on usage patterns, with variables like 'size_rev_small_0' and 'size_rev_small_1' denoting small enterprises in different contexts, and 'size_rev_medium_1' reflecting medium-sized enterprises. These contributions suggest a nuanced influence of firm size on how digital tools are utilised, pointing to varying technological adoption rates and utilisation efficiencies between smaller and medium-sized firms. The red dashed line in the graph acts as a threshold indicator, emphasising the substantial influence these size-related variables have within this dimension.

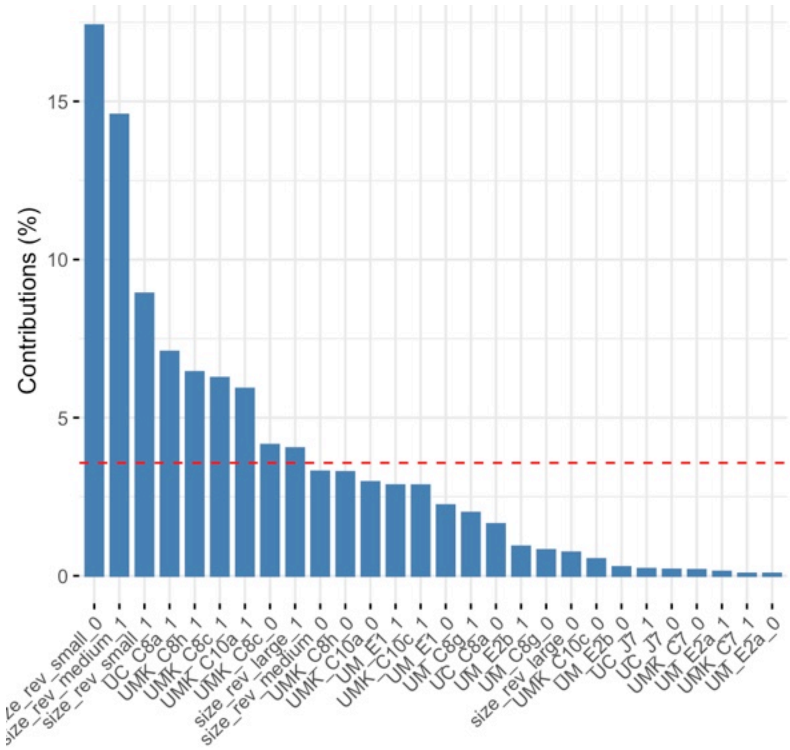


Figure C13: Contributions of Variables to the Second Dimension of Usage in 2014.

Figure C14 depicts the variable contributions to the third dimension of the Usage construct in 2014, emphasising the distinct roles of CRM software in organisational operations. Notably, "UM_E2a_1" and "UM_E2a_0," which refer to the use of analytical CRM software by different subsets within enterprises, alongside "UM_E2b_1" representing the use of operational CRM software, dominate this dimension. This pattern reflects the significant impact of CRM technologies on business practices, mainly how data analytics and operational support from CRM systems contribute distinctly to business operations. The visualisation highlights the pronounced influence of these software categories above the threshold line, underscoring their critical importance in shaping this usage dimension.

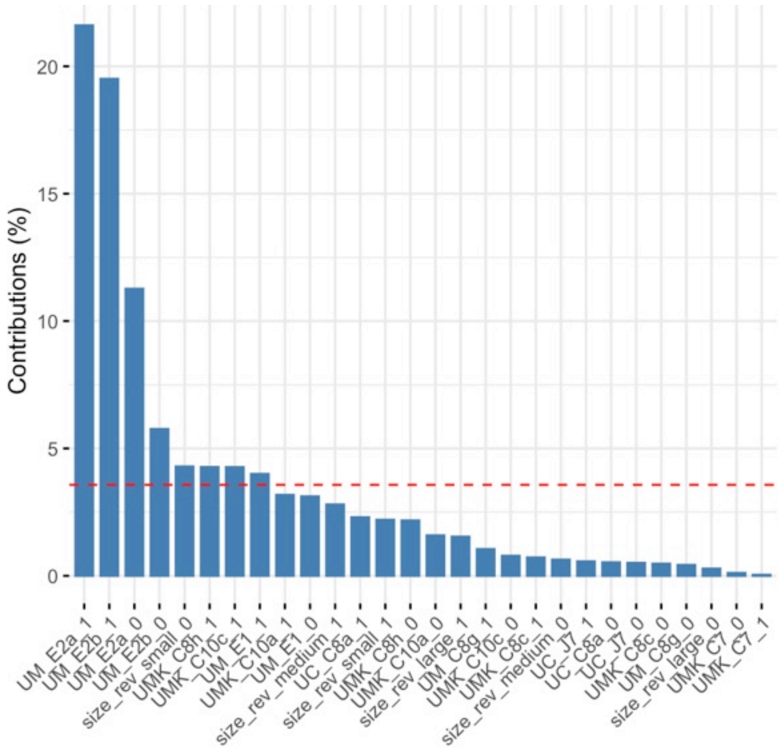


Figure C14: Contributions of Variables to the Third Dimension of Usage in 2014.

Figure C15 illustrates the variable contributions to the fourth dimension of the Usage construct for 2014, with a distinct focus on the influence of enterprise size. The variables "size_rev_medium_1," "size_rev_large_1," "size_rev_medium_0," and "size_rev_large_0" stand out as principal contributors. This dimension significantly highlights the variation in usage patterns between medium and large-sized enterprises, reflecting how their digital technology use differs. The strong presence of these size categories in this dimension suggests that enterprise scale plays a crucial role in shaping the application and impact of digital technologies within businesses. The red dashed line serves as a benchmark, emphasizing the variables that most substantially define this dimension.

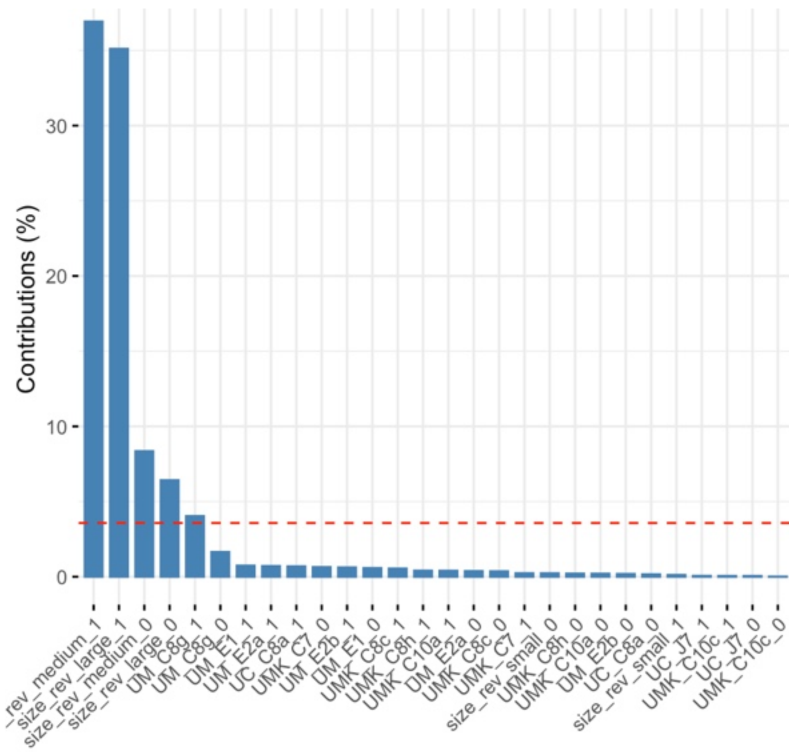
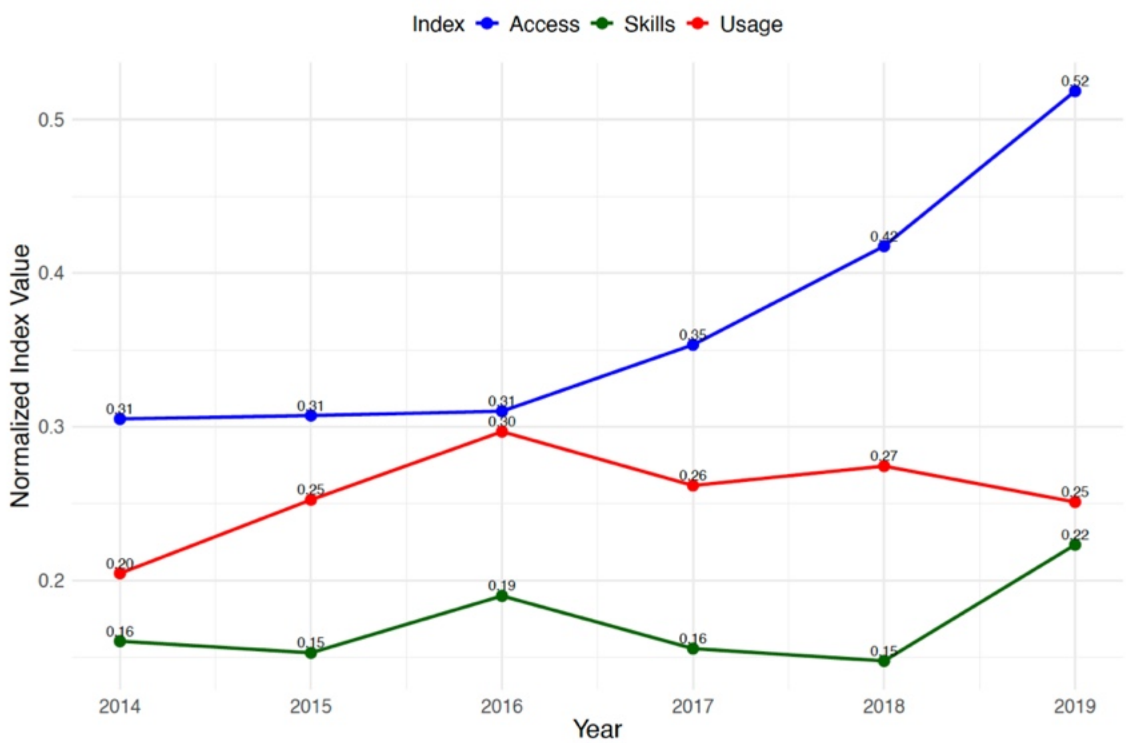


Figure C15: Contributions of Variables to the Fourth Dimension of Usage in 2014.

Appendix D: Composite Indices and Summary Statistics

Composite Indices

Figure D1 provides a comprehensive visual representation of the yearly trends in digital technology integration among Italian firms, focusing on the three main constructs: access, skills, and usage. Each year represents a snapshot of the median normalised index values of these constructs, illustrating the overall patterns of digital technology adoption in general business operations. This aggregated picture helps to understand how firms are navigating the integration of digital technologies over the years. The fact that the usage index is higher than the skills index implies that firms are leveraging their existing digital tools and platforms despite a shortage in digital skills. This underutilisation points to a critical area for improvement, where increased investment in digital training and skill development could



enhance the effectiveness of technology adoption.

Figure D1: Yearly Trends in Digital Access, Skills, and Usage Among Italian Firms (2014-2019).

Figure D2 illustrates these trends, offering a more specific view of how firm size impacts digital technology integration. The access index for SMEs shows a gradual increase over the observed period. In contrast, large companies demonstrate a higher and more volatile access index throughout the period. The initial high values and subsequent fluctuations reflect that large firms are more proactive in adopting digital technologies but also face challenges in maintaining consistent usage levels. This could indicate that large firms are experimenting with various digital solutions but may struggle with integrating and optimising these technologies due to their complex organisational structures, existing systems and shortage of skilled personnel.

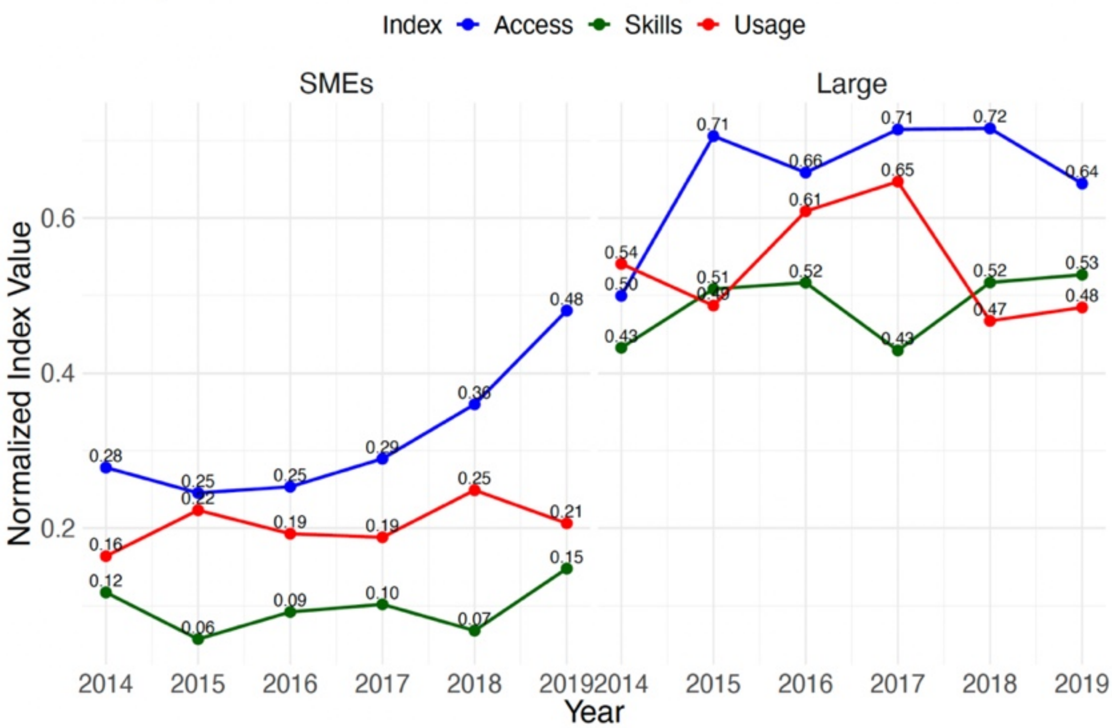


Figure D2: Yearly Trends in Digital Access, Skills, and Usage by Firms Size (2014-2019).

Figure D3 illustrates the trends in access, skills, and usage across four macro sectors: Industrial, Commercial, Services, and Creative Industries & ICTs. This provides insights into how different sectors integrate digital technologies based on their unique needs and operational contexts. These sector-specific insights highlight the varying degrees of digital technology integration across different economic activities, underscoring the importance of tailored strategies to address each sector's unique challenges and opportunities. The impact of supportive policies like the hyper-depreciation measure is evident in the industrial and commercial sectors, while the unique needs and characteristics of the services and creative industries & ICT sectors shape their respective digital integration trajectories.

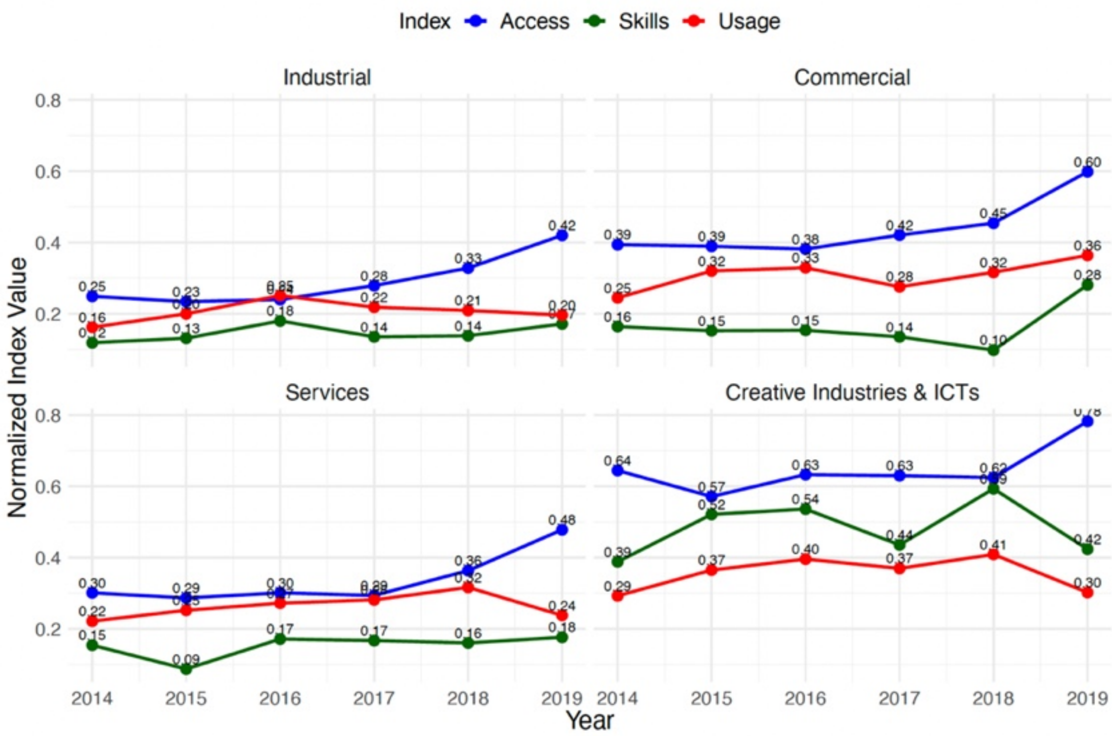


Figure D3: Yearly Trends in Digital Access, Skills, and Usage by Macro Sectors (2014-2019).

Figure D4 illustrates how the integration of digital technology across Italian regions is influenced by persistent disparities stemming from infrastructure, industrial development, and workforce competencies. The Northwest leads in access, skills, and usage, bolstered by robust industrial districts and effective policy implementation, although skills gaps persist. The Northeast and Central regions also demonstrate notable progress in infrastructure and steady, albeit modest, improvements in usage, yet they confront similar limitations in digital skills. In contrast, the South and Insular regions continue to lag, with limited growth in infrastructure, low skill levels, and only modest gains in usage. These regional differences underscore the structural divide between northern and southern Italy, highlighting the need for geographically targeted digital inclusion strategies.

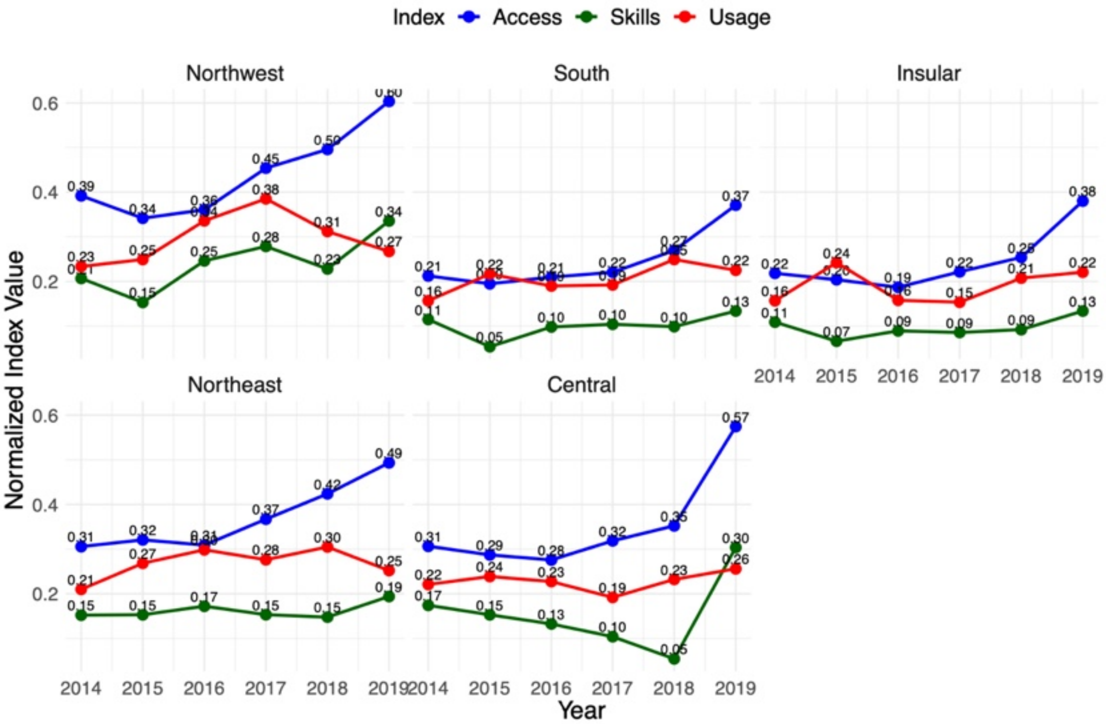


Figure D4: Yearly Trends in Digital Access, Skills, and Usage by NUTS 1 Regions (2014-2019).

Summary Statistics

Tables C4, C5, and C6 provide summary statistics for the constructs of Access, Skills, and Usage for the years 2014 to 2019. Prior to summarizing, the indices for each construct were normalised using the min-max scaling method to ensure comparability and to standardize the values within a range from 0 to 1. This normalisation facilitates a clearer comparison across years and highlights trends and changes in each construct more effectively.

Year	Mean	Sd	Q1	Median	Q3
2014	0.365	0.236	0.168	0.305	0.571
2015	0.360	0.243	0.151	0.307	0.544
2016	0.358	0.240	0.154	0.310	0.526
2017	0.390	0.250	0.173	0.353	0.580
2018	0.426	0.247	0.213	0.418	0.616
2019	0.512	0.260	0.293	0.518	0.756

Table D1: Displays the Annual Summary Statistics of Index Access from 2014 to 2019.

Year	Mean	Sd	Q1	Median	Q3
2014	0.231	0.202	0.055	0.161	0.381
2015	0.239	0.264	0.000	0.153	0.42
2016	0.253	0.268	0.000	0.19	0.445
2017	0.231	0.23	0.005	0.156	0.397
2018	0.246	0.275	0.000	0.148	0.443
2019	0.278	0.241	0.043	0.223	0.463

Table D2: Displays the Annual Summary Statistics of Index Skills from 2014 to 2019.

Year	Mean	Sd	Q1	Median	Q3
2014	0.287	0.244	0.083	0.205	0.478
2015	0.302	0.233	0.114	0.253	0.444
2016	0.332	0.264	0.095	0.297	0.523
2017	0.331	0.272	0.086	0.262	0.551
2018	0.315	0.223	0.128	0.274	0.475
2019	0.299	0.228	0.116	0.251	0.447

Table D3: Displays the Annual Summary Statistics of Index Usage from 2014 to 2019.

Indices Distributions

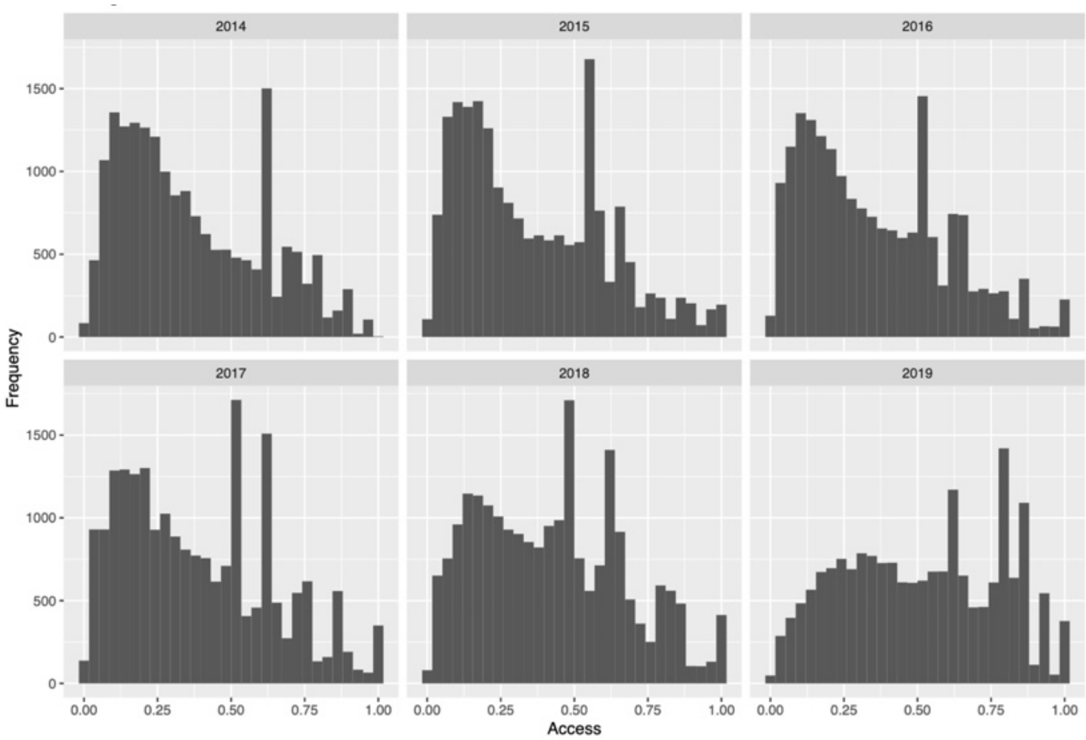


Figure D4: Shows the Distribution of Index Access from 2014 to 2019.

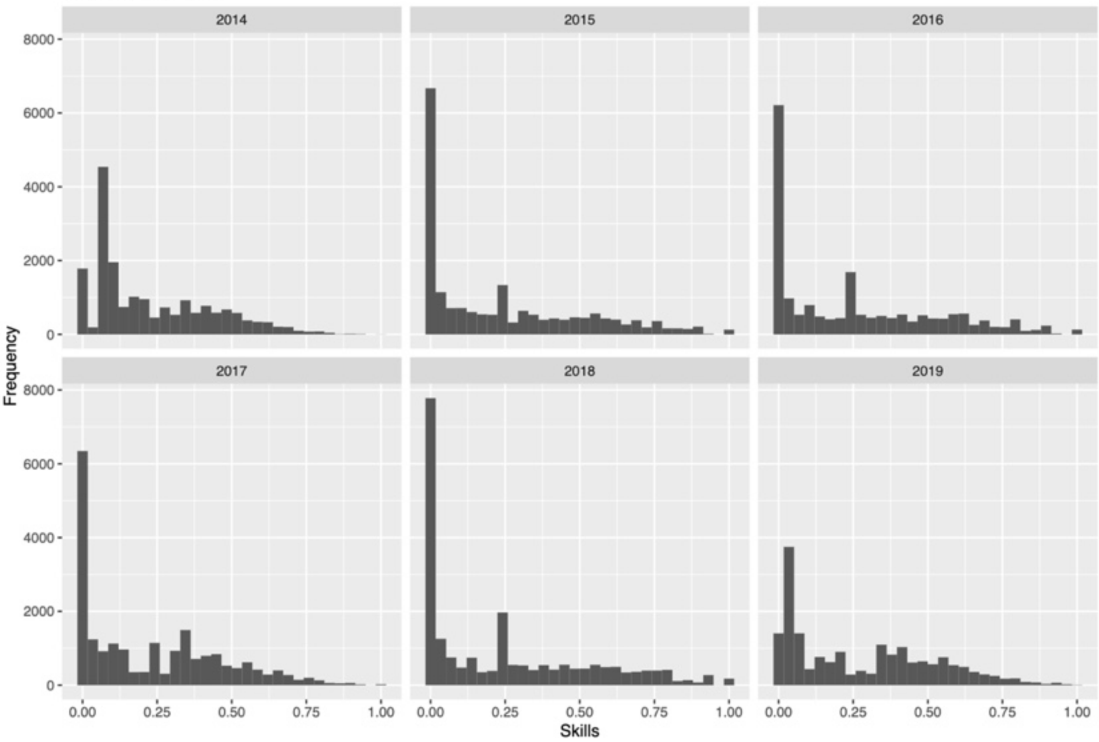


Figure D5: Shows the Distribution of Index Skills from 2014 to 2019.

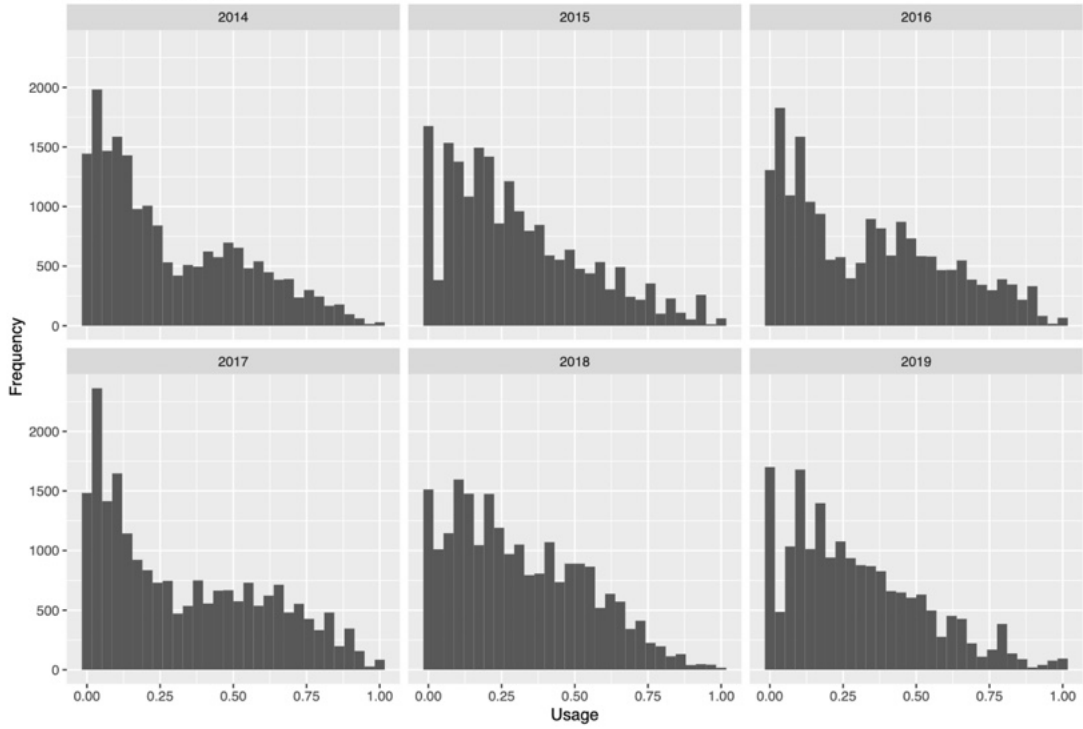


Figure D6: Shows the Distribution of Index Usage from 2014 to 2019.

Appendix E: Sensitivity Analysis

This appendix presents the results of the robustness check conducted to assess the methodological impact of including firm size as an active variable in the factor extraction process for the composite indices of Access, Skills, and Usage. As explained in the Methodology section, the indices were recomputed using identical FAMD and MCA procedures, but excluding the three firm size dummies (small, medium, large) as active variables.

The primary aim was to determine whether firm size significantly affects the dimensional structure or alters the empirical trends of the indices over time and across groups. The analysis includes a comparison of the **median** normalised index values computed with and without firm size, shown across multiple levels: national, firm size, macro-sector, and regional.

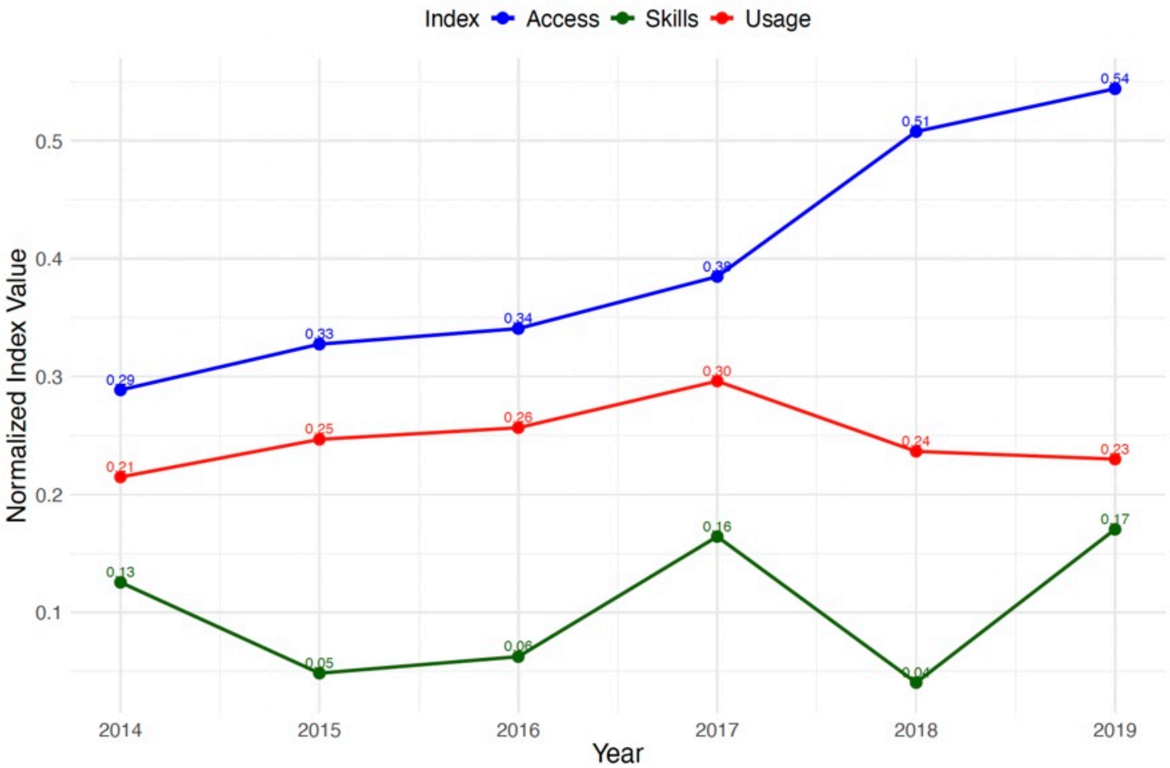


Figure E1: Yearly Trends in Digital Access, Skills, and Usage Among Italian Firms (2014-2019) Without Using Size as an Active Variable.

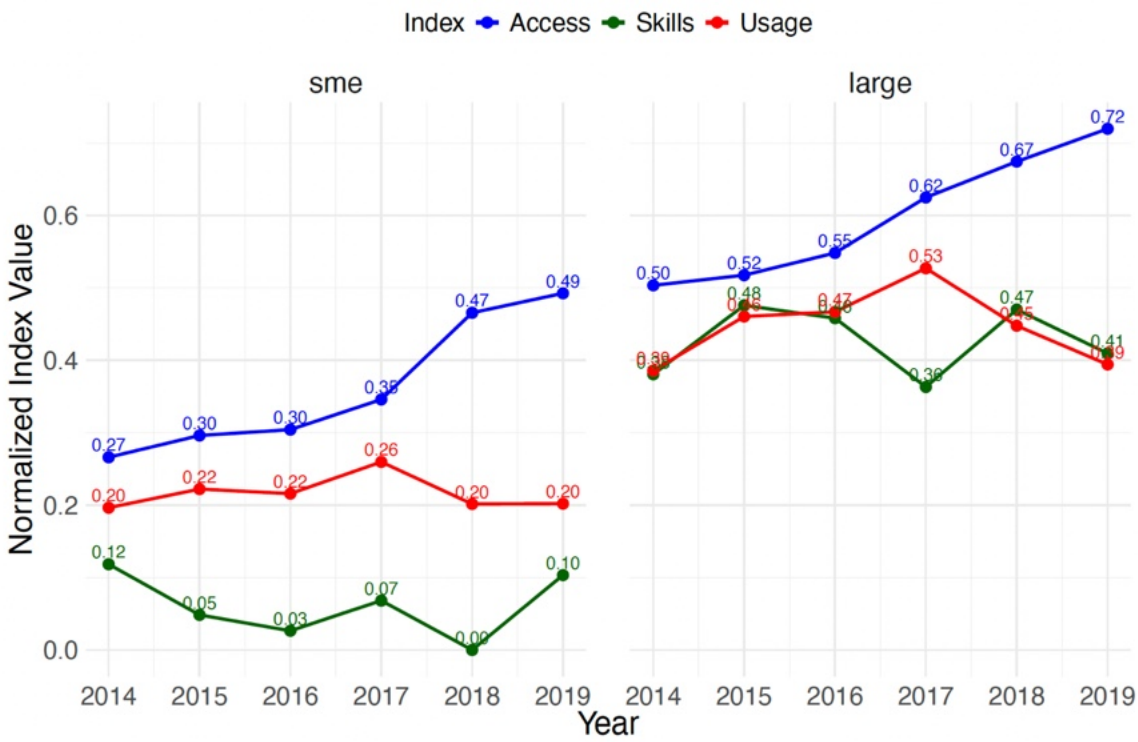


Figure E2: Yearly Trends in Digital Access, Skills, and Usage by Firm Size (2014-2019) Without Using Size as an Active Variable.

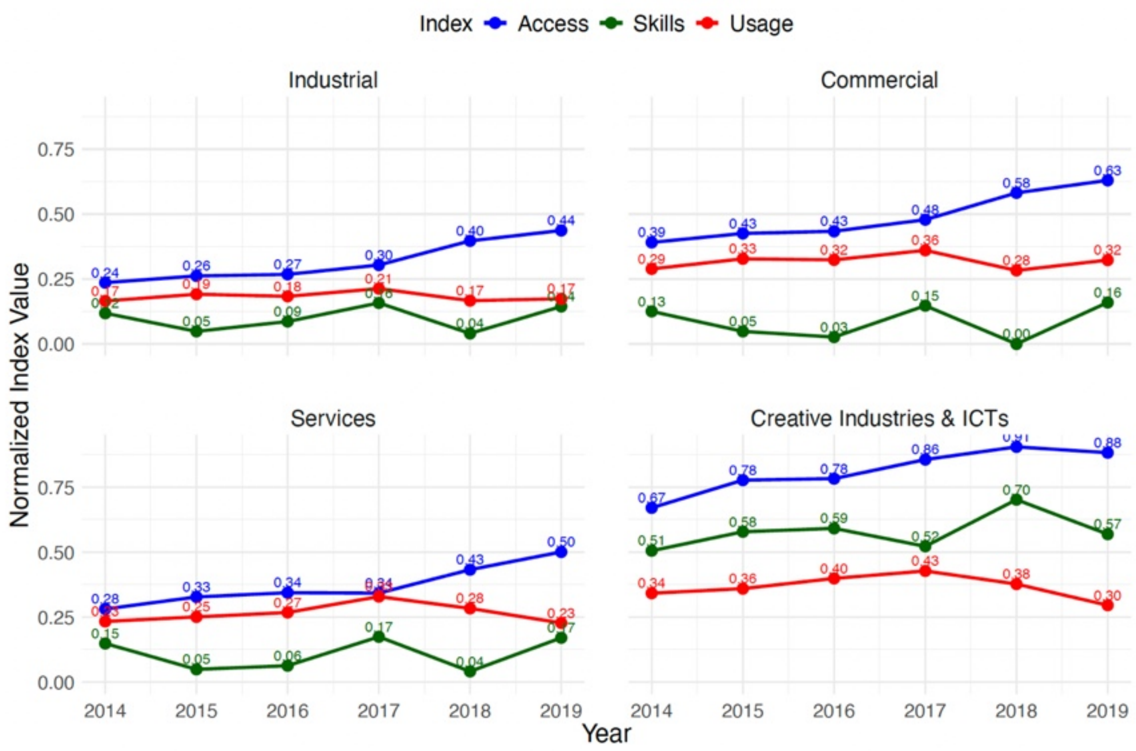


Figure E3: Yearly Trends in Digital Access, Skills, and Usage by Macro Sectors (2014-2019) Without Using Size as an Active Variable.

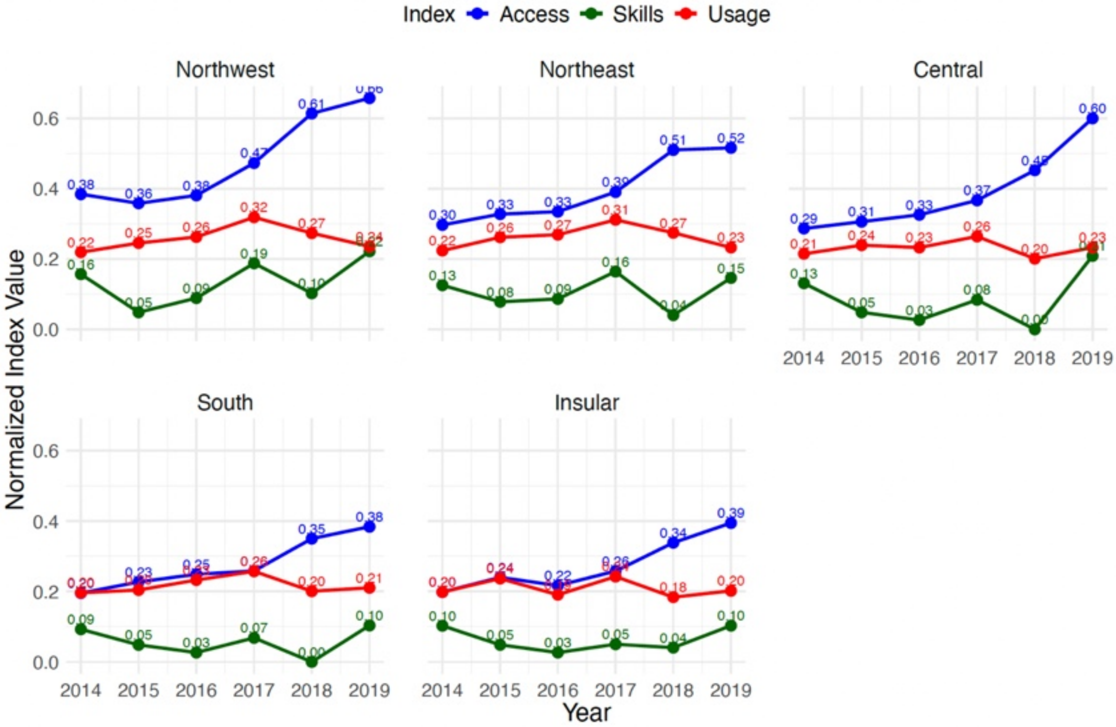


Figure E4: Yearly Trends in Digital Access, Skills, and Usage by NUTS 1 Regions (2014-2019).

As illustrated, the Access index is more sensitive to the inclusion or exclusion of firm size. When firm size is not included as an active variable, access levels appear higher, particularly among SMEs, potentially overstating their infrastructural readiness. By contrast, the Skills and Usage indices remain largely stable regardless of this specification, suggesting these dimensions are less structurally dependent on firm size.

These results confirm that firm size has a material influence on access to digital infrastructure and equipment and support its inclusion as an active variable in the construction of the composite indices. For researchers focusing on structural digital disparities, this distinction is critical.

Disclosure Note

During the preparation of this dissertation, I utilised digital tools such as Grammarly and ChatGPT (OpenAI) to enhance English language clarity, refine grammar, and ensure stylistic coherence. These tools assisted in proofreading and rephrasing selected passages but were not used to generate content or conduct substantive analysis. All academic arguments, empirical results, and interpretations are entirely my own.