

Routledge Studies in the Economics of Innovation

THE DIGITAL ECONOMY AND THE PRODUCTIVITY PARADOX

Michał Włodarczyk and Rafał Wiśła



The Digital Economy and the Productivity Paradox

Despite the billions of dollars invested in digitalization, productivity growth in developed economies remains sluggish and the promised technological revolution has yet to deliver its full potential. This concise book questions why digitalization is not translating into higher productivity and economic expansion, exploring this paradox through the lens of Schumpeter's creative destruction hypothesis.

The book diagnoses and analyses the digital economy as the next stage of socio-economic evolution, with a particular focus on the penetration of digital technologies in the industrial economy. It is geographically limited to the countries of the European Union and the United Kingdom, forming a set of 28 highly developed economies. These countries, characterized by a homogeneous institutional order and varying levels of economic development, provide excellent material for testing and verifying economic hypotheses, including Schumpeter's theory of creative destruction. In relation to Schumpeter's theory, there is indeed observed development of a new sector around a technology that is a radical innovation – the Internet – and the development of technologies based on it, AI, blockchain, cloud computing, etc. However, the rate of technical progress is reaching values close to zero, despite the fact that creative destruction should manifest itself in leaps in productivity. The second point of contention with Schumpeter's theory is the question of oligopolies, which should be the environment most conducive to innovation. However, in the case of the digital economy, productivity growth is most strongly influenced by small and micro-enterprises, which may point to different factors of production than in previous industrial revolutions.

This is a practical guide for researchers and advanced students of economics.

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Introductory remarks

The concept of the digital economy emerged in the 1990s as a result of the rapid development of the Internet. Initially, the Internet was used to exchange digital data between users. With its growing popularity, increased bandwidth and the development of digital platforms, the volume of digital data generated began to grow exponentially (Statista, 2021c). Simultaneously, technologies dedicated to managing digital data – such as Big Data, artificial intelligence and cloud computing – and those designed to improve business processes – such as blockchain, industrial robots and 3D printing – were developed. As technological progress continued, additional technologies capable of generating even larger volumes of data were introduced, including the Internet of Things and autonomous vehicles. Consequently, digital data became the most important resource in the economy. The generation, collection and processing of this data now constitute a key component of modern value chains.

Digital data has ushered in an era of network intelligence, combining human capital – knowledge and creativity – with technology to accelerate social and economic development. The digital transformation is being driven by the information and communications technology (ICT) sector, which is reshaping finance, commerce and government through its products. As a result of digitization, the nature of work has changed, and new virtual products, digital services and digital business models have emerged. All of these changes, initiated by the development of the Internet, have radically transformed economic realities.

The concept of socioeconomic development, when viewed against the backdrop of contemporary reality, allows us to identify two main axioms underlying the logic of modern development. First, the creation of scientific and technological knowledge, along with its effective application in manufacturing processes, determines the capacity and competitive position of economies across all levels and spheres of influence within the sociopolitical environment. Indeed, it is appropriate to speak of enterprises built upon the creation and absorption of knowledge and digital technologies in their manufacturing processes. Furthermore, it becomes justifiable to use the term “digital economy” (based, of course, on knowledge) in a regional context, as new or improved digital solutions are primarily developed in regional

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centers of research and knowledge transfer. This line of reasoning is reflected in the logic of public intervention within the European Union (Wisła, 2014).

Also, it is reasonable to attempt to transpose this issue to the level of a national economy or the economy of a regional integration bloc, as a distinctive feature of the contemporary internationalization process. It is this second research-analytical perspective that is adopted in this book.

When discussing technological change and innovation more broadly, it is necessary to consider the Schumpeterian theory of economic development, one of the central tenets of which is the concept creative destruction as a driver of accelerated development. This refers to technological innovation that generates entirely new value chains and industries, gradually transforming the economy. Some entities or sectors are eliminated in the process. As a result of creative destruction, the market is cleared of inefficient entities, thereby increasing the economy's productivity and accelerating its growth. This hypothesis, which dates back to the early 20th century, is now undergoing a renewed attempt at verification – this time within a digital environment. To assess the validity of Schumpeter's hypothesis in the context of the digital economy, it is necessary to understand the characteristics of the current stage of digital transformation, its dynamics and its impact on changes in total factor productivity and economic development.

This book seeks to verify the validity of this hypothesis. To this end, a multivariate analysis was conducted, part of which involves assessing the impact of digital saturation, as well as human and physical capital, on economic growth. Simultaneously, for the purposes of hypothesis verification and addressing the research questions posed, the phenomenon of the digital economy is narrowed and operationalized into the conceptual construct of the “digital saturation of the industrial economy” – that is, the intensity of digital transformation's penetration into the traditional economy. This involves determining the extent of digital technology usage, the availability of highly skilled digital professionals and the contribution of the ICT industry to production and trade generation.

The authors identify two possible approaches to analyzing the digital economy: microeconomic and macroeconomic. The constantly evolving conceptual framework of the digital economy implies that relying solely on the micro level – focused on the use of individual technologies – can lead to significant cognitive error, given the rapid emergence of new digital technologies and the simultaneous marginalization of others. At the same time, the micro perspective facilitates the classification of digital economy phenomena at a given point in time.

In this study, the authors primarily adopt a macro-level perspective in analyzing the digital economy, which allows for a broader understanding of the phenomenon. This involves the use of macroeconomic aggregates to describe the digital economy, facilitating the tracking of its changes at national and regional levels and offering a more holistic view. This approach enables a comprehensive analysis of the interdependence between the digital economy and both human and physical capital through the application of macroeconomic models. Within this framework, the authors identify a niche for quantifying the changes resulting from the development of the digital economy and comparing them with trends in economic growth

and human capital. By triangulating appropriate quantifiers, it becomes possible to explore the digital economy – as the next stage of economic (and social) development – through the lens of creative destruction.

In the course of reviewing the literature on the phenomenon of the digital economy – primarily in light of the creative destruction hypothesis – the authors highlight the so-called productivity paradox. According to Schumpeter (1960), the introduction of radical technological innovation initiates creative destruction, leading to increased productivity dynamics that, in turn, drive economic growth. This raises a fundamental question: does the digital economy meet the conditions of creative destruction as defined by Schumpeter?

If we assume that the current stage of development – the digital economy – exhibits the characteristics of the installation of network infrastructure, technology and a new institutional order, then a prerequisite for further advancement of this phenomenon is the existence of a developed information society. The issue of the complementarity between high-quality human capital and advanced digitization, as raised in the literature, appears to support this view. A highly skilled workforce, equipped with digital competencies, is able to capitalize on the opportunities presented by new technologies. For executives, a high level of human capital translates into a deeper understanding of the benefits of digitization and a clearer vision for areas of digital implementation.

A review of the scientific literature focused on macroeconomic research perspectives on the digital economy yields the following synthesis. First, the most common approach is a descriptive view of the digital economy, understood as a cross-sectional analysis of the technologies it encompasses, along with their measurement (Sturgeon, 2019). Second, researchers employ macro-level indicators such as: (1) the share of the ICT sector in GDP, ICT employment and R&D expenditures (Barefoot et al., 2019; Duch-Brown, de Panizza and Kholulul Rohman, 2018; Nicholson, 1891); (2) exports of high-tech products (Wysokinska, 2021); (3) turnover, number of customers and the development of e-commerce (IMF, Zhang and Chen, 2019) and digital platforms (Kenney, Bearson and Zysman, 2021); and (4) the level of social capital development through technology availability and market penetration (Lazanyuk, 2019). Third, components of international indices – such as DESI, the ICT Development Index and the Network Readiness Index – are also examined (Spivakovskyy, 2021). Fourth, analyses vary in granularity, ranging from the national level for EU countries (Ardielli, 2017) to the regional level (Strožek, 2016).

The microeconomic perspective is less prominent in the literature. These studies are typically based on surveys and interviews conducted with a narrow group of carefully selected firms – so-called “early movers”. These are companies identified by researchers as leaders in digital transformation. Within this selectively chosen group, the research examines how the tension between consistency and flexibility influences the innovation process in the open market of digital platforms.

On the basis of the assumption that the concept of the digital economy is still evolving, the authors consider macro indicators a more reliable means of measuring its development. Moreover, it is necessary to adopt a sufficiently broad

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perspective – one that analyzes not only the ICT sector but the economy as a whole. This approach enables the classification of EU countries according to their level of digital economy development and helps identify which countries are likely to enter the next phase of digital economic advancement first. The context outlined above leads to the formulation of one fundamental objective of scientific inquiry and the development of the following three research questions and five research hypotheses.

The main objective of scientific inquiry in this book is to examine the nature of the relationship between the digitization of the economy and economic growth in light of J.A. Schumpeter's creative destruction hypothesis.

The research questions posed are fundamental macroeconomic in nature. They are as follows: (1) Does the digital economy represent a form of creative destruction in light of J.A. Schumpeter's theory? (2) Is the currently observed decline in labor productivity dynamics in EU economies a symptom of secular stagnation? (3) Which determinants of digital economy development have the greatest impact on economic growth?

The first research question directly pertains to Schumpeter's creative destruction hypothesis. The second addresses the observed economic slowdown in a selected group of countries, commonly referred to as secular stagnation, which has occurred alongside the development of the digital economy. The third question concerns the determinants of digital economy development and their impact on economic growth.

In addition, the research topic undertaken leads to the formulation of the following research hypotheses: (1) The level of economic development does not correspond directly to the level of digitization of the economy; (2) The level of human capital has a significant influence on the development of the digital economy; (3) The increase in digitization of the economy drives productivity growth, as described in Schumpeter's theory; (4) The supply side of digitization exerts a stronger impact on economic growth than the demand side.

The first hypothesis posits the existence of a digital divide in Europe that differs from the traditional division based on GDP per capita as a measure of development. The authors further assume significant variation in digital saturation among countries with similar levels of GDP per capita. The second hypothesis suggests a complementarity between human capital and the digital economy. The authors propose that the highest labor productivity dynamics are observed in countries characterized by both high levels of digital saturation and high levels of human capital. At the same time, a key question arises: which of the two – human capital or the "digital" sphere – has a greater influence on economic growth? The third hypothesis asserts that the development of the digital economy leads to productivity growth, with all the associated consequences described in Schumpeter's theory. The fourth hypothesis maintains that the supply side of digitization – understood as the creation of infrastructure, research activities and the development of new products – has a stronger impact on economic growth than the demand side, defined as social acceptance of and engagement with new technologies.

The subject scope of our study encompasses the digital economy as the next stage of socioeconomic development, with a particular focus on the digital saturation of the industrial economy. The geographical scope includes the countries of the European Union and the United Kingdom. This group of 28 highly developed economies – characterized by a unified institutional framework but significant internal variation in levels of economic development due to diverse factors – provides a suitable context for multidimensional exploration and the testing of economic hypotheses, including the hypothesis of creative destruction.

The countries in the selected group exhibit significant diversity in terms of employment structure, labor force participation, unemployment, education, innovation and labor productivity. The choice of this group is also motivated by the opportunity to analyze the effectiveness of various digitization policies within the context of the EU single market.

The temporal scope of the study spans the years 2012–2019. This timeframe is determined by the availability of statistical data related to the digital economy and society. Statistical indicators quantifying the digital economy began to be collected, processed and published toward the end of the first decade of the 21st century. However, most of the relevant data – particularly continuous indicators essential to the study’s perspective – have been available only since 2012.

To address the research questions and hypotheses, both taxonomic analysis and analysis based on the neoclassical production function were employed. The applied taxonomic method led to the construction of a synthetic index measuring the digital saturation of European economies. This index incorporates 11 macroeconomic variables mentioned in Chapter 5, which are divided into two groups representing the supply side and the demand side of the digital economy. The variables were standardized, and their weights were estimated using an optimization algorithm. The second method involves a modified neoclassical Cobb-Douglas production function derived from the Nonneman-Vanhoudt model.

The book consists of an introduction, six chapters and a conclusion. The first chapter discusses four definitional approaches to the digital economy (economic, technological, regulatory and social), traces the origins of its emergence and presents a classification of the phenomenon. This chapter is the result of a comprehensive review of research on the digital economy in broad terms.

The second chapter is devoted to the Schumpeterian theory of creative destruction, which is juxtaposed with the realities of today’s increasingly digital world. The productivity paradox of the digital economy is examined alongside the observed phenomenon of secular stagnation. An analysis of the decline in productivity dynamics, with a focus on specific industries, serves as a partial verification of the third hypothesis.

Chapter 3 continues with an analysis of the digital economy, building on the framework established in Chapter 1. The authors describe the transformations taking place in European countries across industrial and agricultural production, digital services, fintech, the labor market and the algorithmization of public administration. This part of the work identifies the stages of digital transformation reached by various economic sectors in European countries. At the same time, it

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supports a broader view of the digital economy – encompassing not only the supply side but also the demand side.

Chapter 4 provides an overview of tools used to measure the development of the digital economy. The international indexes are categorized into four groups, corresponding to the typologies outlined in Chapter 1. These indexes are analyzed in terms of their methodologies, component variables and respective strengths and weaknesses. This chapter aims to identify the dominant methodological approaches used in compiling taxonomic indicators related to the digital economy and innovation.

Chapter 5 builds on the classification of the digital economy phenomenon presented in Chapters 1 and 3, as well as the review of variables provided in Chapter 4. Its purpose is to identify the characteristics that describe the dynamics of digital economy development within the group of European countries under study. This step is essential for advancing the research. The analysis of these variables also serves as a partial verification of the fourth hypothesis.

The core verification of the hypotheses and research questions is carried out in Chapter 6. This chapter outlines the course of the analysis, presenting different variants across the selected analytical groups. Taxonomic indicators are employed to verify Hypothesis One (the traditional and digital division of Europe) and Hypothesis Two (the complementarity of human capital and the digital economy). In addition, a modified neoclassical Cobb-Douglas production function is used to verify Hypotheses Two, Three and Four, and to support the answers to all three research questions.

1 Digital economy

Concept and distinguishing features

1.1 Introduction

The beginning of the 21st century marked the birth of a “new economy” based on digital technologies (Goliński, 2018). Digitization and computerization have accelerated economic processes and changed the functioning model of society. The broader meaning of the term “digitization” was given by Robert Wachal as early as 1971 (Wachal, 1971). He defined a series of changes in society brought about by the increasingly widespread use of digital technologies (digitization of society).

Digital processing of data (collection, structuring, archiving, exchange) provides an increase in business efficiency. This is due to improved operational efficiency (from a micro perspective) and increasing labor productivity (from a macro perspective). As a result, the accelerating pace of technological change with its implementation serves to increase productivity and economic growth.

The term “digital economy” was first used by Tapscott in 1996. In doing so, he described the era of networked intelligence, where dynamic development of the information and communications technology (ICT) sector is being observed. Tapscott (1996) believed that the digital economy can combine knowledge, information and creativity to create wealth in a high-tech economy and promote social development.

The purpose of the first chapter is to synthesize the literature review on the emergence of the digital economy and its different definitional perspectives. The authors analyze the digital economy from economic (change in the economic process), technological (technical development and technological innovation), regulatory (challenges for regulators and risks) and sociological (change in the way society functions, approaches to work and to human relations) perspectives.

1.2 The digital economy in economic perspective

The property of the digital economy is manifested in the digital form of trade (Teo, 2001). The transmission of digital information has radically changed organizational and industrial activities and the basic processes of economics (D’Ippolito, Messeni Petruzzelli and Panniello, 2019). This transmission is mediated by networks of electronic means through which the production, sale and consumption of goods

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and services take place (Cheon and Kim, 2003). Hence, it is possible to consider digital technologies and broadband as the core that makes up the digital economy (Banning, 2016). In this view, the digital economy is the economic form of production of the digital technology sector (Li, 2017). It is driven by the development of the information and communications industry which directly translates into the development of e-commerce (Lane, 1999).

The digital economy can be seen as a kind of conceptual umbrella to describe: markets, communications, data processing and e-commerce (Nathan et al., 2013). By increasing the number of links to the traditional (offline) economy, it is becoming increasingly difficult to define the boundaries of the digital economy. Its impact is already extending beyond business into the lifestyle society (e.g., sharing economy, algorithmization, Big Data) (Capobianco and Nyeso, 2018). Hence, the first difficulty of defining the object of research appears at this stage as already identified. Therefore, the dynamics of the formation of the digital economy (Barefoot, 2018) forces flexibility in the definitions used.

The digital economy, in which an important element of development is the use of the ICT sector, now permeates all areas of socioeconomic life in most developed countries (OUP, 2017). In doing so, it operates at different levels (meso, macro global) as well as structures (Lazanyuk and Revinova, 2019):

- Banking system – mobile and online banking, electronic payments;
- Trade – auction and sales platforms;
- Energy – coordination of raw material supply, energy purchasing, remote reading of consumption meters;
- Transportation – advanced logistics, real-time vehicle tracking, autonomous vehicles;
- Education – remote learning;
- Health – teleportation, teleoperations, surgical robots, patient registries (e.g., the National Health Service’s Internet Patient Account);
- Offices – access to data, documents and applications via the Internet.

The Organization for Economic Cooperation and Development (OECD) defines the digital economy as an economic form whose factor of production is data. Entities in such an economy rely on digital information in their operations, processing it or using it to increase its value. These entities have new business models shaped by new market conditions (digital models, digital services, digital networks) (OECD, 2020).

The concept of the digital economy can be analyzed on three levels (UNCTAD, 2017):

- Core – relates to the ICT and IT sectors. It includes the production of computer hardware, software, ICT services, telecommunications and IT consulting. This level is considered from the perspective of specific technologies such as the Internet of Things, industrial robots, 3D printing, cloud computing, artificial intelligence, blockchain and 5G.

- Narrow scope – includes digital platforms, the digital services they provide (e.g., Facebook and Google) and the sharing economy. This level uses specific technologies to create process innovations and new distribution methods or change approaches to basic economic concepts such as utility and ownership.
- Broad scope – in this sense, the concept of the digital economy extends beyond modern technology industries (e-agriculture, e-administration, e-business, industry 4.0). It also covers finance (fintech and open banking), e-commerce and the labor market (gig economy).

The digital economy is a logical continuation of the development of the concept of the “knowledge-based economy”, which is taking the form of a new economic phenomenon. It is based on the key role of digital information, which drives the qualitative development of civilization. Information, digital resources and digital data are generated, transformed and used on a large scale by economic entities, enabling better use of scientific knowledge in almost all areas of social activity. Digital resources combine data, information, knowledge and technologies. The uniqueness of the development of the digital economy stems from the unprecedented scale of modernization of the traditional economy and the development of the information society. This allows us to formulate a hypothesis about a change in the global economic architecture, in which digital resources and factors replace material resources as the basis (Nazarov, Fitina and Juraeva, 2019).

The emergence of the digital economy was inevitable. The foundations for the digital revolution were laid by the advent of personal computers (PCs) in the mid-1980s, followed by the improvisation of tools for digital design and robotic manufacturing equipment in the 1990s. At the turn of the century, outsourcing and offshoring began to grow rapidly. All this has enabled international companies to develop their capabilities to better leverage what were once disparate corporate IT systems, as well as to improve coordination and interoperability. The growing diversity of ICT devices and software continues to impact the manufacturing, services, transportation and even agriculture (through precision farming) (UNCTAD, 2017). And as the digital economy is still considered a developing and evolving phenomenon (Chen and Wang, 2019), the scale of its influence on economic transformation will continue to grow.

Katz (2017) describes the emergence of the digital economy in three waves:

- The first wave is associated with the use of information and information management systems aimed at data automation for monitoring and reporting. An important point is the spread of telecommunications technologies such as broadband Internet access (fixed and mobile).
- The second wave is associated with the spread of the Internet and digital platforms (markets and search engines).
- The third wave became the starting point for shaping the digital economy. It involves the digital transformation of routine tasks performed by businesses and governments. This advanced phase cannot be achieved without going through the first two stages.

The development of ICT and data processing is reshaping global value chains. This makes it possible to create completely new products and services. These trends can stimulate economic growth, but at the same time disrupt free competition in the market (Capobianco and Nyeso, 2018).

The traditional value chain is a sequence of activities performed by a company that add value to a product. It includes research and development, production, sales and warranty service. This approach was developed by Michael Porter (1985), who believed that the goal of a company is to create value for the buyer that exceeds the costs. The efficiency of a company’s operations is the source of its market advantage (competitive advantage). Therefore, the effectiveness of both individual functions and the entire value chain is important (Johnson, Scholes and Whittington, 2010).

The value chain consists of primary activities, support activities and the margin resulting from their integration. Primary activities consist of:

- Pre-production – research and development, purchasing of raw materials, materials, technology and energy;
- Production – manufacturing, assembly, storage and technical service;
- Sales – distribution of goods, marketing activities, transport, customer service and technical support.

Support activities are processes related to business management. They include human resource management, strategic management and the formulation of vision and development strategies (Kardas and Klineciewicz, 2016) (see Figure 1.1).

Digital elements (digital data, ICT) drive the creation of the digital economy value chain. Owing to the prominent role of virtual data, new industries and new business models are emerging. This enables faster industrialization (including digital industrialization) and the extension of the industrial chain. The new value

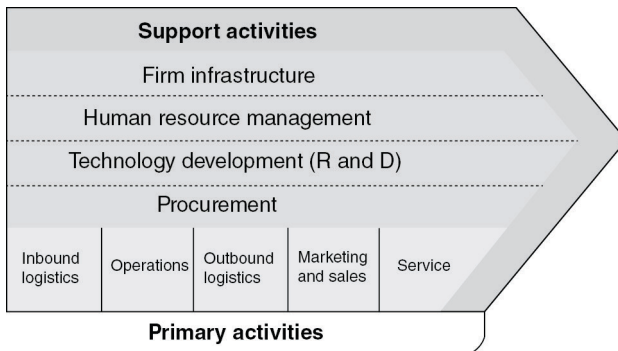


Figure 1.1 Elements of Porter’s value chain.

Source: Borowski (2013).

chain opens up new spaces, consolidates growth points and creates new jobs (Zhenlong, 2021).

Digitization is radically changing the very nature of products, the value creation process, and, above all, the competitive environment of companies. On the basis of a network-centric perspective, companies can achieve competitive advantage by actively shaping the digital environment and connecting companies in the digital environment (Koch and Windsperger, 2017).

Carlsson (2004) emphasized that the digital economy focuses more on new products and activities than on higher productivity. Its key resources are information and a series of economic and social activities carried out by people via the Internet and related technologies (Turcan, Gribincea and Birca, 2014).

The digital transformation of economies in various countries is associated with high expectations for economic growth and improved quality of life. At the same time, there are concerns about job losses, growing inequalities and threats to information security. However, despite these potential risks, digitization has become a dominant feature of global economic development. This has been confirmed and reinforced by the coronavirus pandemic, during which the European Union, the United States and China announced their economic stimulus plans. There was a clear focus on green energy and digitization.

According to the World Bank (2016), the digital economy brings benefits to individuals, businesses and the public sector, such as:

- Lowering information costs, thereby reducing transaction costs;
- Promoting innovative activity;
- Improving operational efficiency;
- Expanding market integration and increasing the number of consumers;
- Creating innovative employment opportunities.

In the context of radical changes in the labor market, it should be emphasized that adaptation to these new conditions requires significant investment, both in terms of retraining the workforce and financing these measures from public or private funds. These expenditures appear to be necessary to counteract the risk of a sharp rise in unemployment that may result from the automation process. In addition, the digital transformation is bringing about changes in the profitability of many traditional sectors of the economy, which requires further investment to adapt to evolving market conditions. Therefore, both the public and private sectors must take decisive steps to facilitate the transition to more innovative and automated work systems, which is crucial for maintaining economic stability and securing the future of the labor market.

1.3 The digital economy in technological perspective

One of the effects of digital transformation is the fourth industrial revolution, a concept developed by Klaus Schwab (2017). In the past, leaders of industrial revolutions benefited from innovative technologies and products. The first

revolution was based on the steam engine, which enabled the mechanization of production in the late 18th century. The second industrial revolution, thanks to electrification, ushered in the era of mass production and assembly lines in the 19th century. After World War II, the third industrial revolution took place, sparked by the invention of the computer and the microprocessor. The fourth industrial revolution is based on digital data, sensor cooperation and the analysis of giant databases by artificial intelligence (Industry 4.0).

The digital economy is an important driver of high-quality economic development. Its potential is evident in the transformation of the traditional economy (Zhao, Zhang and Liang, 2020). In a knowledge-based society, organizations operate in conditions of intense competition, interdependence and economic cooperation. Information and communication technologies are the foundation of the digital economy. However, although ICTs are the basis for digital innovation, they do not in themselves create a knowledge-based economy. Innovation starts with people, through human capital (Anderson, 2008).

The distinguishing features of the digital economy from the traditional economy are (Valenduc and Vendramin, 2016):

- Irrelevance of geographical location – location is less of a competitive advantage. The ability to conduct transactions independently of physical location, similar to remote work or virtual communication, means that Internet access becomes the most important factor;
- The key role of digital platforms – the emergence of three-sided markets, where, in addition to the buyer and the seller, there is a third party (the platform operator). The operator has insight into the subject of the transaction, as well as the frequency and value of transactions;
- The importance of network effects – in the case of digital technologies, consumers benefit as the pool of users of a given technology grows. Facebook and Netflix, with their growing customer base, are becoming more attractive to current consumers, while at the same time finding it easier to reinvest to improve quality and create new content. As a result, the most attractive digital platforms monopolize industries, which, combined with the collection of sensitive customer data, creates a risk of abuse;
- Use of big data – digital data generated at an ever-faster pace is collected in databases (Big Data) and analyzed to identify patterns that would otherwise be invisible. In this way, with a large amount of data at their disposal, database operators can make more optimal and precise decisions.

A 2015 report commissioned by the Federation of German Industries identified four key drivers of digital transformation in European economies: digital data, automation, connectivity and digital customer access (see Table 1.1).

Computerization, together with the third industrial revolution, initiated the creation of digital data. Owing to the exponential growth in data production, it is necessary to systematize and store it. The devices that initiated the fourth revolution (including the Internet of Things) are causing necessary changes in the field of

Table 1.1 Factors of digital transformation development

	<i>Factors</i>	<i>Assistive technologies</i>	<i>Applications</i>
Digital Transformation	Digital data	<ul style="list-style-type: none"> • Big Data • Wearable devices (wearables) • Internet of Things 	<ul style="list-style-type: none"> • Demand protocols • Data-driven routing protocols • Preventive maintenance
	Automation	<ul style="list-style-type: none"> • Robotics • Additive manufacturing 	<ul style="list-style-type: none"> • Drones • Autonomous vehicles
	Connectivity	<ul style="list-style-type: none"> • Cloud computing • Broadband Internet 	<ul style="list-style-type: none"> • Smart factory • “Pure” digital products • Remote maintenance • E-commerce
	Digital customer access	<ul style="list-style-type: none"> • Social networks • Mobile internet/apps 	<ul style="list-style-type: none"> • Infotainment • Fourth party in logistics

Source: Roland Berger (2015).

Table 1.2 Number of data produced worldwide (in zettabytes)

<i>Year</i>	<i>Produced Data</i>
2010	2
2011	5
2012	6.5
2013	9
2014	12.5
2015	15.5
2016	18
2017	26
2018	33
2019	41
2020	64.5
2021	79
2022	97
2023	120
2024	147
2025	181

Source: Statista (2021c).

archiving and personal data protection. There are calls to recognize personal data protection as a human right (see Table 1.2).

Personal computers, mobile devices and wearables have caused the number of annual data created worldwide to increase by 3100% (from 2 to 64 zettabytes) between 2010 and 2020. The number of people with access to the Internet exceeded in 2021, with 4.6 billion people (Statistica b). The development of devices included in the Internet of Things, such as autonomous cars, smart factories, smart homes and smart cities, will bring this figure to nearly triple by 2025 (181 zettabytes per

year) (Statistica c). The number of devices connected to the Internet of Things will grow from the current 10 billion to 25.4 billion in 2030 (Statista, 2021a).

Digital technologies can be considered disruptive innovation, which changes the status quo (Kerber, 2016). It is important to distinguish digital technologies into (Nathan and Vandore, 2019):

- ICT – hardware (e.g., drones, industrial robots, wearable devices);
- Digital content (software, online advertising, online design, online media, online business).

Among the key technologies mentioned are (UNCTAD, 2017, pp. 1–13):

- Advanced industrial robotics.
 - o Industrial robots are a sector worth \$24.35 billion globally (in 2020). By 2026, its value is expected to increase to \$52.85 billion (compound annual growth rate (CAGR) for 2021–2026 is 14.11%);
 - o Global spending on industrial robots has increased since 2000 from \$3.9 billion to \$16.4 billion in 2020, with further growth estimated to reach \$24.4 billion in 2025;
 - o The use of robots is possible in the automotive, chemical, construction, electronics, food, machinery, pharmaceutical and optical industries;
 - o During the 2020–2025 period, the largest growth in the industrial robot sector will be in Southeast Asia (Japan, China, India). North America and Europe will see lower rates. Germany remains the leader in Europe, followed by France and the United Kingdom;
 - o Major players in this market include ABB Ltd, Yaskawa Electric Corporation, Denso Corporation, Fanuc Corporation and KUKA AG. The market is highly fragmented and competitive (Mordor Intelligencea–d).
- Artificial Intelligence (AI).
 - o The term artificial intelligence includes a collection of technologies: Deep Learning, Machine Learning, Natural Language Processing, Machine Vision;
 - o AI finds potential use in the healthcare, legal, financial services, advertising, manufacturing, agriculture, transportation and automotive sectors;
 - o The global artificial intelligence market was worth \$93.53 billion in 2020 with a projected CAGR of 40.2% between 2021 and 2028;
 - o The main driving force behind this technology is the availability of large databases in market entities and government institutions;
 - o Major companies in this market are: AMD, Arm Limited, Baidu, Google, IBM Watson Health, Microsoft, Nvidia, Intel (Grand View Research).
- Internet of Things.
 - o Developments in wireless connectivity, advanced data analytics and cloud computing have made it possible to connect devices to each other. In this way, they can exchange data among themselves. This can include sensors, smartphones, wearable devices, autonomous cars or industrial robots.

In the concept of Industry 4.0, the Internet of Things is the technological center enabling a new approach to production, management and development;

- o Applications of the Internet of Things are possible in manufacturing, transportation, retail, healthcare and energy industries. The main benefits are increased efficiency in storage, energy consumption or supply chain;
- o The global value of this market is expected to grow from \$761 billion in 2020 to \$1.39 trillion in 2026 (CAGR of 10.53%);
- o Major players in this market are: Cisco Systems, Google, IBM, Microsoft, Huawei Technologies (Mordor Intelligence b).
- Cloud computing.
 - o It includes a set of concepts like Infrastructure as a Service, Platform as a Service and Software as a Service;
 - o The global cloud computing market was worth \$312 billion in 2020 with an annual growth rate of 24.1%. Global revenues reach \$312 billion. The dominant one is Software as a Service (47% of total revenues) (IDC);
 - o The digital platform market was worth \$47.29 billion in 2020, while the Application Platform Market was worth \$9.18 billion in 2019. They offer access to business applications and are used in the enterprise market.
- Big Data.
 - o Advanced big data analytics allows management, visualization and pattern discovery;
 - o It is used in the financial, health, entertainment, logistics and government sectors;
 - o The global market was valued at \$13.21 billion in 2020 and is estimated to grow in value to \$52.75 billion by 2026 (CAGR of 26.2%);
 - o Major companies in this industry are: Oracle Corporation, Amazon, Google, Microsoft, IBM (Market Research Firm).
- Additive Printing (3D Printing).
 - o The technology allows objects to be created from scratch, creating new possibilities for design and production. 3D printers use polymer, metal and ceramic materials;
 - o 3D printing is used in the automotive, aerospace, healthcare (prosthetics manufacturing), energy and electronics industries;
 - o The global market value was \$13.7 billion in 2020. By 2026, it will grow to \$63.46 billion (CAGR of 29.48%);
 - o Major companies in this sector are: Stratasys, 3D Systems Corporation, ExOne, General Electric Company (GE Additive), Proto Labs (Mordor Intelligence c).
- Digital payment systems.
 - o In 2020, the global digital payments market numbered \$5.44 trillion (calculated by transaction value). Digital payments are estimated to grow to \$11.29 trillion by 2026 (CAGR of 11.21%);
 - o The development of digital payments has been boosted by the pandemic. However, there had already been rapid growth in cashless payments,

including mobile payments via phones, virtual purses and the fintech sector (Businesswire.com, 2021).

- Blockchain.
 - o Distributed registry technology was originally the hope of the IT sector. It quickly became the basis of cryptocurrencies, along with its most famous representative – Bitcoin. Blockchain enables transactions that are cheaper and faster than traditional systems;
 - o It can be used for payments, exchange trading, smart contracts, digital identity, documentation, supply chain management and GRC (Governance, risk management and compliance) management and digital currency issuance;
 - o The biggest impact is on the real estate, energy, government, financial, health, entertainment and transportation sectors;
 - o The value of the global market reached \$3.67 billion in 2020. By 2024, the market will grow to \$15.1 billion (CAGR of 69.3%);
 - o The largest companies developing this technology are: Deloitte, IBM, Eric Industries, Circle Internet Financial Limited, Ripple (Marketwatch.com).
- 5G.
 - o The new connectivity standard provides low latency data transfer, higher speeds and the ability to support a large number of devices. The previous 4G (LTE) standard provided a maximum transfer of 100–300 Mbps, while 5G provided 10–30 Gbps. Such bandwidth will allow the development of the Internet of Things, smart factories as part of “Industry 4.0,” autonomous cars and smart homes and cities;
 - o The global market for 5G-based services reached \$1.62 billion in 2020 and is expected to grow to \$424.63 billion in 2026 (CAGR of 155.5%). By 2030, the global economy will gain \$330 billion from 5G development (PWC);
 - o The global infrastructure market will grow from \$3.5 billion in 2020 to \$53.8 billion in 2026;
 - o The main companies developing 5G are: Cisco Systems, HP, NEC, Nokia, AT&T, Verizon, Huawei.

Chen and Wang (2019) points out that the main driver for the development of the digital economy is the adoption and development of outsourcing centers on a global scale. The digital economy as based on digitization and globalization requires internationalization, heavy investment in ICT and the freedom to trade in a virtual environment (Accenture, 2016).

Digital transformation uses blockchain technology in financial transactions. It enables high-level contracts between entities (Mesropyan, 2016). Blockchain used in cryptocurrencies (including Bitcoin) becomes an electronic currency. The intangible form of currency (including traditional currencies like the US dollar) is a fundamental component of the infrastructure of the digital economy (Pschenichnikov, 2017).

1.4 The digital economy in regulatory perspective

As with any industrial revolution, digitalization brings benefits, but at the same time the economy needs protection from regulators. Among other things, protection of

competition to combat excessive monopolization is needed. For this, it is necessary to understand the global mechanisms that provide benefits to the economy (Akman, 2019). Disruptive innovation, by its radical impact on the market, if left unregulated leads to monopolization which distorts competition.

An essential component of the digital economy is the generation and collection of digital data. Protecting this data becomes a key task. However, there is currently no effective mechanism for their protection. Wiebe (2017) outlines the need to regulate the right to market and protect industrial data in the digital age. In the coming years, the development of industrial robots, further automation and autonomous cars will expand the pool of data generators, which will only exacerbate the problem.

The OECD has recognized many areas where digitization and data-driven innovation impact competitiveness. In 2016, the digital economy was selected as a strategic theme for the OECD Competition Committee among which are the following (Capobianco and Nyeso, 2018):

- The relationship of the digital economy to legislation and innovation;
- Challenges with antitrust;
- Practical challenges with law enforcement;
- Development and evolution of certain industries.

Vatamanescu, Nistoreanu and Mitan (2017) argue that the development of the digital economy raises questions about consumer protection mechanisms, privacy, intellectual rights and competition policy. In this regard, the European Union has concerns about the inconveniences of the digital transformation and how it will affect consumers and the business environment.

The development of ICT has led to the emergence of a new economic model (the digital economy) in a short period of time, which is credited with the potential to stimulate business competition and consumer welfare. However, given the rapid pace of popularization of Internet access and the doubling of gross revenues of some digital sectors year-on-year, there is a risk that the regulatory response may be too late (Gazzola et al., 2017).

Not all digital technologies pose the same regulatory challenges. The label of digital technologies can be quite misleading, as it actually represents a wide range of technical aspects of artifacts. This is important because in an increasing number of regulatory policy documents, “digital technologies” or the “digital economy” appear in broad terms. Unfortunately, these terms appear without a clear definition and without distinguishing between different issues related to technical artifacts (Beaumier et al., 2020).

The development of the digital economy has created new goods – virtual products. These are goods delivered in online form and hence are intangible, according to Alfred Marshall’s theory. Thus, in this approach, they are information goods with a digital form of distribution. Goods by definition satisfy human needs. Thus, we consider databases, ebooks, websites or movies as information goods. The virtualization of goods creates the need to protect the producer against illegal copying. The regulatory challenge in this case is the rationing of virtual

goods only to the group of people who participate in the costs or pay a premium (subscription). At the same time, the fee for Internet access cannot be equated with a fee for specific virtual goods (Czetwertyński, 2017). This limits the phenomenon of free-riding, which manifests itself in the illegal circulation of software, music, movies or data.

Through the development of ICT technology and the use of virtual goods (including software and algorithms), companies can easily expand their operations transnationally (scalability). This is referred to as cross-jurisdictional scale without mass (cross-jurisdictional scale without mass). Technology companies actively participate in the economic life of many countries, influencing the lives and decisions of citizens. At the same time, they do not feel constrained by national laws or taxes (Śledziwska and Włoch, 2020). For this reason, European Union countries are working on the introduction of a digital tax to effectively tax corporations that are part of the digital economy – the so-called digital giants. In order to protect domestic markets from American and Chinese digital corporations, Spain has introduced a 3% tax on revenues from the Spanish market. A 2% tax has been introduced by the United Kingdom (księggowosc.infor.pl). All of these behaviors are aimed at creating a single digital market that will allow free flow of digital goods, increase efficiency and improve access to information.

One of the solutions used to regulate the digital economy is regulatory test environments, commonly referred to as regulatory sandboxes. They create a special isolated environment for testing the possible effects of introducing a new technological solution. In this way, it is possible to:

- Safely conducting an “experiment”;
- Rapidly verify innovations and evaluation by the regulator;
- Reduce barriers for innovators;
- Accelerate the pace of solution implementation.

All this is done with limited risk to customers. Currently, regulatory sandboxes operate in more than 20 countries. Since 2018, the KNF’s regulatory sandbox has been operating in Poland. The leader and pioneer in Europe is the UK regulator Financial Conduct Authority (FCA), which has allowed the United Kingdom to achieve a leadership role in the development of the fintech sector in this part of the world. On average, 32% of applications to participate in the FCA sandbox are approved and allowed to be tested (Marchewka-Bartkowiak, 2019).

An important phenomenon is data extractivism and its negative social effects. Digital technology corporations wishing to acquire goods (digital data) create processes centered around extracting as much data as possible from users. In the literature, this is referred to as data mining or data gathering/data harvesting. Data extractivism has applications in areas such as cryptocurrency mining, financialization or the study of the human genome and human behavior. The problem from a regulatory perspective is a kind of exploitation of the workforce, which is drained of the data it holds. A user has a certain amount of potential data that he or she can generate such as search results, photos, videos, news and documents. In

addition, digital technologies track a person's activities and can collect information about his or her location (GPS locator), music preferences (streaming services), political views (social networks), diet (food delivery apps) and others. Companies in digital industries use the collected data to better target groups for their products. Similarly, large data sets are an invaluable resource for the development of science. Unfortunately, this breeds room for abuse by companies collecting user data.

Researchers raise the issue of global data pollution (data pollution), which has no less impact than coal or iron ore mines (Kröger 2020a, 2021). According to 2008 estimates, the electronics industry used 36% of the global supply of tin, 25% of cobalt, 15% of palladium, 9% of gold, 2% of copper and 1% of aluminum (GHGm, 2008). The electricity consumption of the global digital economy (counting only use and cloud computing) corresponds to the energy consumption of Canada – the sixth largest energy consumer (Cook, 2014). This shows that the impact of digital data extractivism needs to be understood as a regulatory challenge in both environmental (rare earth mineral extraction), energy (operating computer networks and server farms) and social (data harvesting) terms.

The problem of electro-waste also remains. As in any traditional sector, the digital economy, despite its focus on virtual goods and services, generated 53.6 million tons of electro-waste annually in 2019. This is a 21% increase over 2015 (44.4 million tons). Projections call for an increase of another 39% by 2030, when global e-waste production will reach 74.7 million tons. It is estimated that only 17.4% of e-waste is documented, collected and recycled.

Added to this is the problem of digital colonialism, that is, the control of the infrastructure of the digital economy (datasets, digital platforms, technologies) by the largest companies. This breeds social inequality, as access to new solutions is only for privileged groups (better off, living in specific countries, speaking specific languages) (Couldry and Mejias, 2019).

1.5 The digital economy in social perspective

Digital transformation is affecting the way society functions, both from the side of the labor market and required skills, as well as interpersonal relations. For this reason, economic sociology, having a sociological methodology for studying economic phenomena, becomes important. An approach characterized by a special interest in tradition, generating its own research data and accepting of limited human rationality distinguishes it significantly from economics. It also allows a deeper understanding of the mechanisms governing economic behavior, taking into account the broader social and cultural context (Morawski, 2001).

In the course of their development, industrial societies gave increasing importance to knowledge, which was treated as a resource. Thus was born the concept of the knowledge economy, which is distinguished from earlier industrial versions by seven aspects (Suchacka, 2014):

- High investment in research and development activities;
- Growing importance of exports and international relations;

- Employment growth in knowledge-intensive industries (high technology);
- The emergence of knowledge-based enterprises;
- Growth of the service sector's contribution to GDP and employment;
- Growing importance of formal and informal networks in socioeconomic life;
- New properties of knowledge as a strategic resource.

With the demands of the 21st century, the need for specific competencies, referred to as “21st Century Skills”, has become crucial for those entering the job market. These skills include collaboration, communication, digital competence, civic awareness, problem-solving ability or critical thinking. Voogt and Roblin (2012) note that the transformation of societies to knowledge-based economies has significantly raised the importance of soft skills in a professional context.

Seeking to classify 21st century skills, Claro (2012) lists:

- Mastering ICT applications to solve cognitive tasks at work;
- Skills that are not related to technology, as they do not relate to the use of any specific software;
- Skills that support higher-order thinking processes;
- Skills related to cognitive processes to foster continuous employee learning.

Among the determinants of the development of a knowledge-based economy are (Europeanportal.eu):

- Human capital – high-level professionals familiar with new technologies, knowledgeable in foreign languages and able to work creatively and effectively;
- Universities and scientific research institutions – these entities are providers of knowledge (know-how and technology). They create a climate conducive to development and innovation. Close links between the R&D sector and businesses are essential to increase the efficiency of knowledge utilization;
- Financial and lending institutions – provide capital for high-risk innovative investments. A developed financial sector helps reduce capital barriers for those creating the knowledge economy;
- Technical infrastructure – includes ICT technologies and the ways in which they are adopted by the public.

Flexible production and service delivery systems are causing profound changes in the workplace, such as flatter management structures, decentralized decision-making, information sharing, task forces, inter-organizational networks and flexible working conditions. These changes require new skills known as 21st century skills. The name indicates that they are related more to current socioeconomic development than to the industrial mode of production of the 20th century (Van Laar et al., 2017). Precisely for this reason, with the development of a knowledge-based society and rapid integration of ICT, digital skills are necessary for employment and participation in society. Their absence is referred to as digital exclusion (Ananiadou and Claro, 2009).

The demands placed on employees in today's labor market are characterized by a high degree of complexity and interactivity, which implies the need for employees to possess not only advanced technical skills, but also the ability to effectively select and use information. These skills are crucial not only in the professional context, but also in private life. In addition, adaptability to rapidly changing work conditions and requirements is considered equally important. A study by Ahmad et al. (2013) points to the growing importance of comprehensive employee preparation, which includes both the technical aspects and soft skills needed to effectively work in a dynamically changing work environment.

The center of concentration of people with digital skills are postindustrial cities. In them, creative and digital industries accumulate, which create so-called "digital content". This creates digital clusters, where large technology companies locate their headquarters (Nathan, Vandore and Voss, 2019). Through these companies, cities create their brand and identity, which attracts small technology companies. These startups benefit from the production and consumption potential that digital clusters offer (Włodarczyk, 2020). At the same time, through globalization and automation of the production of goods and services, thousands of jobs have been eliminated or relocated to developing countries (Levy and Murnane, 2012).

The digitization of the economy is considered a key driver of innovation, economic growth and social change (Olbert and Spengel, 2017). Thanks to this, there is an increase in the efficiency of the economy and an improvement in the quality of life. Efficiency is understood as better use of the resources at hand. The assumption of productivity growth and economic growth as a result of the development of the digital economy is increasingly questioned.

Empirical studies show that increasing the level of investment in ICT has a positive impact on GDP (Zahra, Azim and Mahmood, 2008). At the same time, the strongest impact of ICT on GDP dynamics is recorded in countries with little telecommunications infrastructure (Datta and Agarwal, 2004). However, analyses of the economies of European Union countries (2006–2016) show a negative relationship between ICT development and economic growth (Sylwestrzak, 2018).

The most important factor in endogenous economic growth is the digitization of all aspects of human life. It leads, thanks to artificial intelligence, to more efficient use of resources, which translates into positive per capita GDP growth rates. Studies in the United States and Europe show that investing in ICT helps achieve high growth in every sector of the economy (Remache and Belarbi, 2019). This is because digital technologies are changing the existing economic systems with their traditional production and consumption processes. Today, digital technology is creating a new reality for governments, people, businesses, organizations and markets and provides a new promising growth path for every country (Khalimon et al., 2018). So, just as the steam engine and electricity once did, they are modernizing everything in their path.

At the same time, despite the rapid increase in business spending on ICT, the digital economy (understood as mobile technologies, the Internet, cloud computing) has not yet brought visible improvements in productivity (Van Ark, 2016). The definition of productivity has been considered to be the achievement of greater

production and sales results while using fewer resources. However, it is important to remember that the digital economy is still in its formative stages. Its impact on productivity will be assessable only with developed digital technology. In the meantime, productivity in industrialized countries is struggling with a marked decline in the rate of growth, which raises the question of a possible productivity paradox in the digital economy (Gorelova, 2016).

1.6 The problem of measuring the digital economy

In the scientific literature, the most common studies on the economy and digital transformation are descriptive analyses, including a comparative one. The work of Sturgeon (2019) crosscuts the history of the emergence of the digital economy, the fourth industrial revolution and the ICT sector. He identifies major technologies like cloud computing, Big Data, the Internet of Things and artificial intelligence, and describes their application. He similarly describes new products and services like digital platforms, e-commerce, mobile payments, e-logistics, digital design (VR) and crowdfunding.

Skvarciany and Jureviciene (2021) detail five aspects of studying the digital economy and rely on OECD nomenclature: infrastructure, social capital, technology adoption, labor market and finance. The study identifies the weights each aspect has. Innovation, labor market and finance turn out to be the most important, respectively. The least important is social capital. Thus, they demonstrate how indicators measuring the level of development of the digital economy should be built.

In the work of Kuzovkova, Kuzovkova and Sharavova (2019), the most common approach is evident, that is, the use of existing indicators (Digital Economy and Society Index [DESI], ICT development index, Social Progress Index, Network Readiness Index, Global Innovation Index, etc.). Here, the issues of social capital, technology availability and sector development are captured, from a macro perspective. A similar approach can be found in the work of Afonasova et al. (2019) in which changes in the position of individual countries in successive editions of the rankings are analyzed. Studying the digitization of Ukraine on the basis of the Network Readiness Index, DESI and Digitalization Score (Spivakovskyy et al., 2021) makes it possible to see aspects where the digital economy requires additional support in terms of developing its own platforms or fighting industrial espionage.

Attempts to gain a deeper understanding and measure the phenomenon of digital transformation and the digital economy usually take the form of analysis of ICT or the level of social development. The latter approach is based, among other things, on an analysis of the number of mobile and fixed-line subscribers and the prevalence of Internet use and mobile. The values of these variables are compared over time in terms of the development of the digital economy. Lazanyuk and Revinova (2019) thus compare the countries of the BRICS group (Brazil, China, India, Russia, South Africa). The comparison of the aforementioned variables made it possible to synthetically rank the countries and identify Brazil and Russia as the

countries with the highest level of development of the digital economy. Strożek and Jewczak (2016) compare Polish provinces in terms of the development of the digital economy using indicators such as the number of active telephone lines, the number of households with computers, the number of Internet users, software spending in industrial enterprises (their share of GDP) and the number of cable TV subscribers. Ardielli (2017), in order to compare EU countries in terms of ICT use in the cultural sector, used variables such as the number of people reading articles online, using streaming video and music, listening to online radio, reading blogs, storing data in the cloud and buying cultural goods (books, movies, music, event tickets) online. Using these data, a model was created based on the MAPPAC multi-criteria decision-making method. The study confirmed the high level of digital development of Luxembourg, Sweden, Finland, Denmark, the Netherlands and the United Kingdom. The lowest on the list were Croatia, Poland and Romania.

The second approach, that is, wanting to describe and measure the digital economy in terms of the ICT sector, uses aggregate data for individual countries. A Bureau of Economic Analysis study (Nicholson, 1891; Barefoot, Curtis and Jolliff, 2018) focused on the development of the digital economy in the United States. The researchers compared the share of the ICT sector relative to other components of GDP and its changes over time, changes in value added generated, employment in ICT and changes in individual components of the digital economy. In 2017, the digital economy accounted for 6.9% of the US economy, value added grew at an average annual rate of 9.9% (between 1998 and 2017), with support services, telecommunications, software and e-commerce accounting for the largest share of value added creation. Declining during the period under review was the role of computer hardware whose share fell from 20% in 1997 to 5% in 2017. A similar use of the ICT sector's share to measure the level of development of the digital economy is evident in the Duch-Brown study (Duch-Brown, de Panizza and Kholulul Rohman, 2018). It uses the added value of the ICT sector as a share of national GDP in individual highly developed countries. The dominance of Taiwan, Ireland, South Korea, Romania and Sweden is apparent. In addition, the ICT sector is broken down into three subgroups: ICT manufacturing, telecommunications, computer services. For each subgroup, the number of companies, employment and share of GDP were analyzed.

An attempt at a sectoral approach to studying the digital economy is also being analyzed by researchers through the lens of e-commerce. Digital commerce is measured by turnover and the number of online transactions. This measurement is supported by underlying data including the number of Internet users, broadband access prevalence and ICT employment levels. This is how Longmei Zhang and Sally Chen (2019) conducted an analysis for the International Monetary Fund on China's digital economy. This analysis, however, is cross-sectional, focusing on many aspects from employment to GDP contribution, which makes it difficult to create a synthetic indicator and rank countries by their level of digital economy development.

Measuring the effects of digitization with data on export volumes is also apparent. Wysokinska (2021) for this purpose uses data for EU countries from

2015 to 2018 on total exports, exports of high-tech products and the dynamics of export changes. The study describes financing methods and the concept of the European Digital Single Market as supporting the digitization process of European countries. The author argues that it is possible to achieve sustainable development goals through digital technologies, if only through medical innovations and efficient cost-cutting production.

Kenney, Bearson and Zysman (2021) focused on digital platforms in the context of their growing strength in the US market. The analysis is based on the number of stores (electronic, medical, newsstands, restaurants) and digital platforms that integrate with their business models, such as transportation platforms like Uber. In addition, the annual sales growth of major platforms like eBay, Shopify and Amazon are analyzed. The study shows that 70% of service industries, representing more than 5.2 million businesses, can be influenced by one or more platforms. This study shows that Amazon's growth trajectory has transformed existing industries and sectors.

Potential data with which such an indicator could be strengthened are the numbers of patents in the ICT sector, electricity production per capita and the price of energy, which are necessary for the development of the digital economy. One can also come across studies that refer to digital transformation on a micro level, that is, from the perspective of individual companies (Nambisan, Wright and Feldman, 2019). Brunswicker and Schecter (2019) examined how the tension between cohesion (coherence) and flexibility affects a developer's digital innovation trajectory in an evolving and open platform market. To do so, they used relational event modeling based on information from 480 developers involved in the development of 700 applications on the open nanoHUB platform. According to the researchers, coherence in the digital platform environment leads to the creation of new solutions, while flexibility leads to stable results.

Verstegen, Houkes and Reymen (2019) focused on the ways in which digital technologies are used to organize work and achieve enterprise goals at the collective level. The quantitative study was conducted using interviews, observation and data from two architecture firms. The use of digital technologies is organized into collectives that perform reflecting and configuring-in-use to achieve the realization of goals at the collective level.

Shaikh and Levina (2019), wanting to examine how organizational decision-makers choose the open innovation community as their alliance partner, used the grounded theory method and interviews with 39 executives from 2 technology companies. The research led to four main indicators: the friendliness of the community to the corporation; the health of the ecosystem; the viability of the community; the value to the company from the community's products and services.

Eitneyer, Bendig and Brettel (2019) focused on whether the social capital of crowdfunding ventures is related to the involvement of backers as sources of and code developers. The main question was whether sponsor engagement translates into increased product innovation. Measuring engagement in the stream of social capital theory and consumer engagement, the researchers used surveys and data from 710 crowdfunding ventures. According to the researchers, differences in the

strength and intensity of different types of social ties, reciprocity and identification with the crowdfunding community affect ventures' interactions with sponsors. Policy makers should combine public innovation funding systems with private reward-based crowdfunding platforms.

Wang et al. (2019) focused on business angels and their impact on information asymmetry. The question was whether the dominance of business angels on platforms means that digitization only benefits large investors and perpetuates the financial imbalance associated with conventional financing. Data was collected on 50,999 unique investors and 1,151 unique campaigns from July 2012 to August 2017 on a UK crowdfunding platform. The work shows that social investors complement angels in large campaigns and help fund small campaigns that don't attract angel interest. Angel investments are more informative than community investments. Regulators need to further encourage and facilitate the flow of information, which reduces market friction while protecting collective investors from misrepresentation.

Saadatmand, Lindgren and Schultze (2019) investigated how the interplay of technology architecture and governance mechanisms generate platform organizations that create different levels of commitment from complementors. They used data garnered from a 12-year (2002–2013) joint platform initiative and of the Swedish road transport industry. Horizontal platform organization leads to high levels of complementor involvement, while vertical and modular platform organizations generate lower levels of this involvement.

Miric, Boudreaa and Jeppsen (2019) examined the relevance strategy of large and small app developers and how they try to capture value on digital platforms. For the study, they surveyed mobile app developers in the Apple App Store and used a linear regression model. Formal protections such as patents, copyrights and trademarks are rarely used over informal protections such as lead time and versioning. Larger companies use a combination of formal and informal protections, while smaller companies rely mainly on informal protections.

Balsmeier and Woerter (2019) focused their study on the impact of adopting new digital technologies on job creation and destruction. They used a survey on digitization and employment conducted among a group of Swiss companies. They found that investments in digitization increase high-skilled employment and decrease low-skilled employment. No impact was found for digital technologies other than those involving machines.

Forman and Zeebroeck (2019) analyzed under what conditions digital adoption increases the flow of knowledge between locations in companies. They used econometric analysis of a large dataset of Internet adoption and patent citations across company locations between 1992 and 1998. Adoption of the Internet increases the likelihood of citation between pairs of company R&D locations. The effect is greater when the pair works in similar research areas or the research is less specialized.

1.7 Summary

Digital economy is the umbrella term for digital technology, telecommunications, e-commerce and data processing markets. The use of information and communication

technologies is changing the way society, the labor market, government and all sectors of the economy operate.

The emergence of the digital economy is a natural consequence of the development of the knowledge economy. The role of digital information, which is responsible for the qualitative development of civilization, has become crucial. Free access to information and the ability to transform it facilitates the use of scientific knowledge to create innovations, which accelerates technological development. The paradigm of factors of production is changing. In terms of the digital economy, the role of land is being taken over by digital data, automation is taking the place of labor, communications infrastructure is the new physical capital and digital customer access is the social capital.

The labor market is also transforming. The need for digital skills is emerging, conditioning employment. These are both soft skills (teamwork, communication, problem solving, critical thinking, creativity) and technical skills (digital literacy). This indicates the growing importance of a widespread understanding of digital technologies and the development of high-level human capital to generate and implement innovations.

The emergence of the digital economy resulted from the popularization of computers and easy access to the Internet. The development of specific digital technologies (Internet of Things, robots, 3D printing, cloud computing, 5G, blockchain, artificial intelligence) created opportunities for process innovations and digital platforms. Digital goods and services and digital business models have emerged, and approaches to elementary economic concepts such as utility or ownership (sharing economy) have changed. New digital value chains are creating jobs, consolidating growth points and taking stronger advantage of network effects. Ultimately, in addition to the new technology sector, traditional industries are being restructured, creating e-agriculture, e-government, e-business, Industry 4.0, fintech and e-commerce.

The growth of the digital economy raises regulatory challenges. Failure to take steps to protect competitiveness leads to digital monopolies. The urgent need for the legislation to protect and regulate the circulation of industrial and personal data becomes crucial. It is necessary to define the limit of protection of intellectual rights to stimulate the development of innovation while not harming competitors and customers. An important step toward modern market regulation is regulatory sandboxes as safe places to test the effects of new technological solutions.

A review of the scientific literature on the digital economy leads to the following synthesis. In works characterized by a macroeconomic research perspective, the most common approach to the digital economy is descriptive. To measure the development of the digital economy, researchers use macro indicators (such as the ICT sector's share of GDP or R&D expenditures) and analyze factors that are components of well-known and international indices. The microeconomic perspective is less prominent in the research literature. These studies are based on surveys and collected from a narrow group of selected companies – the “early mover” or “snowdrop”. These are the companies that the researchers identify as leading the digital transformation and therefore representative in the study of the digital

economy. The study shows a positive impact of digital implementation on productivity, engagement, innovation and cooperation.

The limitations of sharply defining the digital economy phenomenon due to its ever-evolving nature are apparent. Focusing on specific technologies will knock a lot of detail out of the picture. At the same time, it means that definitions are quickly rendered obsolete by the emergence of new technologies and the marginalization of others.

2 Schumpeterian theory of economic development

2.1 Introduction

The emergence of the digital economy is a phenomenon with technological, economic, social and regulatory backgrounds. It follows three previous industrial revolutions, most notably the emergence of the Internet and digital data. The ICT sector, together with technological innovations, has changed the perception of productivity, including labor productivity, and has provided a potential basis for the next stage of dynamic economic growth.

The purpose of Chapter 2 is to anchor the phenomenon of the digital economy in economic theory. Digitalization is based on digital technologies that change the competitiveness of businesses and entire economies. The use of radical innovation (disruptive innovation) naturally connects with Joseph Schumpeter's theory of economic development.

In this chapter, the authors focus on:

- Analysis of Schumpeterian theory, including a discussion of the role of the entrepreneur, innovation, and creative destruction in creating cyclical economic development;
- The contemporary perception of Schumpeter's achievements;
- Confronting the hypothesis of "creative destruction" and the related cyclical nature of the economy with the digital transformation, serving to answer questions one and two and verify hypothesis three, as mentioned in the introduction;
- Analysis of productivity changes associated with the development of the digital economy;
- The phenomenon of secular stagnation as a possible explanation for the paradox of declining productivity in the digital economy.

2.2 Schumpeterian theory of economic development and innovation

Joseph Alois Schumpeter was an Austro-Hungarian-born economist who is one of the most significant figures in the economic world of the 20th century. He was born in the small town of Třešť, in what is now the Czech Republic, in 1883. The town

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had several industrial plants. One of them was founded by Schumpeter's grandfather and was managed by his father (Josef Alois), who thoroughly modernized it through mechanization. After his father's death, Schumpeter and his mother moved to Graz and then to Vienna. His stepfather was a retired field officer of the Austrian army. Because of his high social status, Schumpeter was able to attend elite schools. He continued his education at the Faculty of Law at the University of Vienna, where he studied economics and law under the tutelage of Eugen von Böhm-Bawerk. In his later years, he was a lecturer at the universities of Chernivtsi and Graz, and served as Austria's Minister of Finance (1919–1920) and President of the Biedermann Bank (1920–1924). In 1932, he moved to the United States, taught at Harvard and co-founded the Econometric Society. At Harvard, he collaborated with the Economic Theory Club Group, with Paul Samuelson, Paul Sweezy, Oscar Lange and Shigeto Tsuru, among others. He believed that the use of quantitative methods would open up new possibilities for economics. Despite this, he himself did not use advanced mathematical formulas in his theoretical arguments (Mikosik, 1993).

In his work, he referred to a number of social sciences: sociology, economic history, political science, statistics, history of economic thought and economics. In his research vision, he distinguished between two concepts – “statics” and “dynamics” – which are reflected in the real economy. This distinguishes his methodology from that of J.B. Clark, who emphasized the abstract and merely methodological meaning of these two concepts. Statics and dynamics are separate fields with different research objects, methods and research problems (Mikosik, 1993). In *The Theory of Economic Development* (1911), he replaced the term “statics” with “circular flow” and the former “dynamics” became “development”. He referred to long-term economic development that fluctuates as economic evolution.

Statics is a balanced model, where small changes in data occur continuously. In circular flow, the economy “quietly follows the beaten tracks” and factors of production do not create new connections. Behavior in the economy is routine, based on tradition and past experience with production methods. Thus, these are societies where only simple repetitions in the economic system are observed. Demand and supply balance each other out in this system, as all products must be sold, because in their production the capacity of the sales market is taken into account based on experience. In the static model, Schumpeter in statics adopted Say's law stating that supply creates its own and correspondingly equal demand. In production, no profit is created; there is only rent and wage as compensation. Thus, there is no capital or credit except for commercial and merchant credit. Money is passive in this arrangement and serves only an intermediary function. Thus, it is a stagnant society, with no significant technical or production changes (Schumpeter, 1908).

A dynamic situation is characterized by economic development, that is, abrupt changes resulting from new and previously unknown combinations of factors of production. A feature of such development is a qualitative change that throws the economic system out of static equilibrium. At the same time, it does not tend to return to the initial state. Each disruption resulting from economic development causes the system to constantly seek a new equilibrium point. It is important here

to distinguish between quantitative change (which would force the market to adapt) and qualitative change (which causes a reconstruction of the internal structure).

Crucial to Schumpeter's theory is the distinction between growth and economic development. Quantitative changes, involving a gradual increase in the volume of production or the level of wealth, constitute economic growth. Economic development is characterized by qualitative transformations that force a change in the equilibrium point. Schumpeter believed that inside a developing economy, there is "a source of energy that destroys equilibrium by itself". Schumpeter's methodological challenge was to identify the source of this energy and to properly classify the factors that upset the equilibrium. He referred to the "self-supporting driving forces of economic development" as innovations, which are realized by entrepreneurs (innovators), and the development generated by them is a discontinuous phenomenon. Development driven by innovations coming from within the economy shapes new equilibrium states all the time. In this way, Schumpeter introduced concepts such as profit, entrepreneurship and interest.

Worth noting is the methodological individualism evident in Schumpeter's work. In his approach, he explains economic phenomena by reducing them to individual causes. This means that the explanation of economic processes should begin from the behavior of individuals. Methodological individualism consists of observing the actions of individuals and then generalizing them on the basis of the regularities in behavior that occur. The description of behavior that is ultimately obtained makes it possible to explain economic and social phenomena. Schumpeter recognized that individuals in the economy assume different social roles. He assumed that some unique individuals possess a non-hedonistic motivation for action, risk-taking and self-realization. These unique motivations are most strongly manifested in entrepreneurs, to whom Schumpeter attributed the most important social role (Schumpeter, 1960)

A central tenet of Schumpeter's methodology is the endogenous and self-perpetuating nature of innovation. The innovation impulse creates the prospect of higher profit, by which a wave of innovation and imitation (diffusion of innovation) is created. The diffusion of innovations causes a decline and then disappearance of excess profit, and this leads to economic depression. Adjustment processes occur in the market. The driving forces (innovation) cause cyclical economic development, which creates new conditions for the emergence of the innovation impulse (see Figure 2.1).

Joseph Schumpeter's considerations focused largely on economic development. In his vision, the evolution of economic life results from endogenous forces. When endogenous developmental forces do not act on the economic system, the system is stable. Without the intervention of endogenous developmental forces, the system will constantly strive for an ideal state of equilibrium, but never achieve it. In his discussion, Schumpeter analyzes the endogenous factors of change, which consist of three groups:

- Changes in buyers' tastes;
- Changes in production resources;
- Abrupt changes resulting from new ways of using factors of production (innovation).

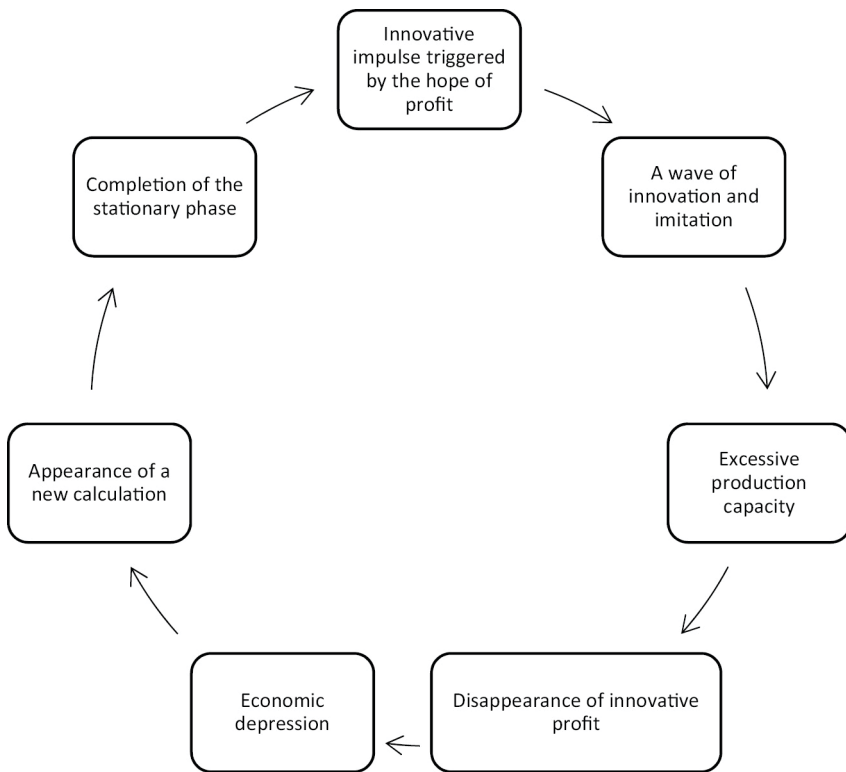


Figure 2.1 Layout of overall endogenous development.

Source: Mikosik (1993).

From his observations, the precedence of production-related changes that affect consumer tastes emerged. Changes in buying behavior are derived from producers' actions (marketing and educational actions). He categorized changes in productive resources as "growth factors", that is, responsible for the increase in wealth, and therefore economic growth. Changes in productive resources are continuous, so that they are absorbed by the system without disruption (adaptation). For this reason, his further consideration of the important factors of economic development was based only on innovations. Only they, by leaps and bounds, significantly change economic life. On this theoretical basis, Schumpeter concluded that tools dedicated to the dynamic model were necessary to measure them.

Schumpeter in his work *Theory of Economic Development* (1911) described five cases of such changes:

- Creating and marketing a new product with new properties;
- Development of a new production method;
- Finding a new market;

- Discovering new sources of raw materials;
- Introduction of a new organization (e.g., the creation or liquidation of a monopoly).

In Schumpeter's theory, three roles emerge: inventor, innovator and imitator. The separation of the first two roles is due to the demarcation of invention and its transformation into innovation. On the basis of this, the "Schumpeter triad" was created: invention – innovation – imitation. Invention is a scientific or technical fact. An uninterrupted stream of invention creates potential technical progress, which is a necessary but not sufficient condition for innovation. Development arises when invention is put into practice. A new solution is an innovation until a newer, previously unused method or solution is implemented. The spread of innovation through imitation, adaptation and diffusion is called diffusion of innovation in Schumpeter's theory. Changes that are invention and imitation are continuous, while innovations through discontinuity are unique. He used the term innovation to describe the ability to implement new solutions, that is, to generate innovations. This is because innovations are new combinations of material elements and the creative power of man.

Schumpeter saw the life cycle of a company in a form similar to human life. A company investing in innovation causes existing production equipment to age through what is known as "moral wear and tear". A company's survival depends on "keeping pace with the innovation process". Failure to keep up with the innovation process results in the rapid demise of the company, which is what Schumpeter explained through the impermanence of businesses. New companies require "new people" to emerge, who can implement new ways of doing things with fresh eyes. Among the obstacles to the innovation process, Schumpeter finds traditional societies, stagnant economies and lack of courage to take risks.

Initially, Schumpeter recognized that radical and major innovations required the creation of a new company. Its creation was dictated strictly by the realization of a particular innovation, by which resistance and adversity were overcome. Over the years, he changed this view, recognizing that innovation is best developed in oligopolistic capitalism, known as "structured" capitalism. The change meant that innovation is carried out largely by already established companies.

At this point it is worth adding that Schumpeter understands the essence of competition between market players as rivalry with innovation. This rivalry is a creative destruction that affects entities unable to implement new products or production methods. Competition prompts companies to offer attractive products in terms of quality and price, which results in a rich, varied and ever-changing offer for consumers.

At the same time, Schumpeter viewed the role of monopolies differently. He considered monopolization natural when an entrepreneur introduces an innovation. Until its dissemination (diffusion of the innovation), the profit obtained by him is due to his monopoly. With further innovations, the monopolist's role changes. In addition, he states that under perfect competition, the propensity for

innovative change is reduced by the immediate possibility of imitation. Antitrust restraint can therefore limit innovation in the economy, since the main motivation of entrepreneurs is the promise of additional profit solely for him as a reward for the risks and costs incurred. For this reason, Schumpeter tends to favor an oligopolistic market structure as the one most conducive to innovation. They can conduct research and development on a large scale and invest in the development of new ideas. This type of activity cannot be afforded by small businesses (Mikosik, 1993).

Schumpeter assumed supply-side sources of innovation and an entrepreneur who is its creator. The concept of the entrepreneur itself comes from A. Smith and was later developed by J.B. Say, L. Walras and A. Marshall. As they understood it, the entrepreneur is the owner of capital, creating jobs, organizing and managing economic activities for profit

Of the aforementioned economists, it was Schumpeter who most detailed the role of the entrepreneur in the economic and social process. In his view, the term entrepreneurship appears additionally. He thus defines the entrepreneur's peculiar state of mind, which gives him the power to solve problems, to go beyond his own resistances and limitations and to act "against the current in unknown circumstances". What is important is the lack of class affiliations. Entrepreneurs are distinguished only by their entrepreneurial state, present at the time of the innovation. So it is a kind of social elite, with the distinction that membership is not hereditary. The group of entrepreneurs are individuals "haunted by the spirit of entrepreneurship", which is what makes them unique. They are surrounded by conservative imitators who realize imitations (Mikosik, 1993).

In order to realize new factor applications (innovations), credit is necessary. Banks finance innovation through the creation of credit, which shifts and creates purchasing power. Schumpeter even believed that capitalism begins with the creation of credit. Capital, thus collected, was described as a lever that allows the factors of production to be directed to new forms of use. Capital is therefore not a separate factor of production, but a bridge between the entrepreneur and goods. For this reason, it does not create pure profit by itself, and the entrepreneur does not have to own the capital. Borrowed funds are returned after a certain period of time to the capitalist with an appropriate interest rate.

For Schumpeter, the source of profit was the entrepreneur's innovative activity. The most common approach is lowering the cost of producing goods while keeping the same price. Other types are cheaper sources of supply or better organization of labor. Producing and selling an entirely new good allows prices higher than goods previously produced. Profit accrues to the entrepreneur who, through his creative actions, outperforms the competition. The entrepreneur's profit, however, is temporary, as the pioneer is followed by imitators which leads to the disappearance of profit. The disappearance of profit leads to a new state of equilibrium, where all income is attributed to wages and pensions (Schumpeter, 1939).

Schumpeter understood as the study of the business cycle the analysis of the economic process under capitalism, whose characteristic is cyclicity. In his research, he distinguished three approximations of reality:

- Two-phase *cycle* – introduces a primary impulse into the model in the form of a few entrepreneurs acting innovatively. They disrupt the equilibrium of the model and create an opportunity for windfall profit. The vision of profit encourages imitators to implement innovations in their enterprises. All innovation activities are financed by capital borrowed from banks, which expect it to be returned with interest. In this simplified model, Schumpeter assumes full utilization of factors of production, so new innovative firms must take over factors of production from old firms by auction. This causes inflation, which hits consumers and entrepreneurs who do not innovate the hardest. Once mature innovators' investments and new commodities are on the market, entrepreneurs' profits begin to be realized and loans are repaid. A period of "self-deflation" begins, when banks absorb the monetary surplus they have created by creating credit, causing prices to fall. Reducing prices only hurts old non-innovative companies, so that market imbalances occur. Demand becomes saturated, the cost-price relationship becomes less and less profitable, the risk of failure increases, the rate of investment falls, and thus the inflow of purchasing power slows down. There is a displacement of old companies by new and innovative ones ("creative destruction"). Prices fall until all loans are repaid and unsuitable companies are eliminated from the market. After that, a new equilibrium is reached with price levels lower than before, but higher real incomes. Another breakout of equilibrium is achieved by the emergence of a new innovation.

In this approximation, there are two phases (rising [boom] and falling [recession]), the limit point of which is the suppression of the inflow of additional purchasing power and the decline in investment.

- Four-phase *cycle* – introduces new elements to the analysis such as psychological reactions of individuals to economic phenomena. The individual assumes further economic phenomena on the basis of the previous economic trend. In the boom phase, based on optimistic economic data, individuals begin to speculate on the future level of prices, income and demand which gives rise to a "secondary wave of expansion", reinforcing the boom phase. In the downward phase, the crisis is prolonged by the pessimistic predictions of individuals, which transforms "creative destruction" into "anomalous liquidation" amid hysterical panic.

Secondary waves of boom and crisis give birth to new phases: recovery and depression. Between recession and depression and recovery and boom, the economy passes through states of equilibrium neighborhoods. Through these approximations, Schumpeter departs from perfect equilibrium (typical of stationary conditions) in favor of imperfect equilibrium – which better reflects conditions considered "relatively normal" by entrepreneurs.

The problem with this approximation is determining when a new cycle begins. Schumpeter assumes the natural operation of market mechanisms. However, he does not specify whether innovative forces or investment activity push the economy toward equilibrium. He only specifies that at some point entrepreneurs will make replacement investments, especially in areas where there is a favorable change in demand. In this way, the economy moves toward

a new equilibrium through the recovery phase. In a state of equilibrium, the degree of risk and uncertainty is reduced, which provides favorable conditions for the resumption of innovative activity.

The new equilibrium, however, is characterized by underemployment. This is due to the learning process of entrepreneurs and their gaining experience. Producers consciously create reserves that allow them to react quickly depending on changes in demand. According to Schumpeter, equilibrium with underemployment can be achieved by entering the boom phase.

- *Diagram of three cycles* – Schumpeter distinguished three types of business cycles that differ in length. He named them after their authors: Kondratiev, Juglar and Kitchin. When trying to relate the cycles to each other, Schumpeter found that they remain in a certain interdependence to each other. Each longer cycle is a trend for the shorter cycle. In turn, the upward phase in the longer cycle is the prevalence of prosperity in the shorter cycles. They also have a structure defined in relation to each other. Each Kondratiev cycle contains six Juglar cycles and each Juglar cycle contains three Kitchin cycles within it. The Kitchin cycle is, from a businessman's perspective, economic fluctuations over short periods of time (3–5 years). The Kondratiev cycle is long waves, which are “good times or bad times” for the entrepreneur because they last 45–60 years. The Juglar cycle is an intermediate wave with a length of 7–11 years.

The economic surge is the result of uneven diffusion of innovation. Schumpeter explains it in two ways. First, it is due to the differential maturation time of innovations. Each innovation may have its own cycle, which runs alongside the cycles of other innovations overlapping each other. The second explanation is based on the complexity of innovations. Large innovations that realistically transform the economy in many ways are adapted in stages, and sometimes by unfavorable price-cost relationships or when market absorption are temporarily interrupted. This proves that the long waves of the cycle result from the intensity of the short waves (Schumpeter, 1939).

The cyclical nature of development is therefore due to innovative changes. They are the impetus for the start of the cycle. The qualitative and quantitative effects of innovations depend on which phase of the cycle they occur in. Qualitative changes of endogenous origin remain the primary source of development. Every crisis leads to a point of equilibrium; every cycle leads to economic development and progress. As a result of the cyclical nature of the economy, successive equilibrium points are reached (Mikosik, 1993).

Thus, the Schumpeterian vision implies a key role for the entrepreneur, who takes the risk of creating new products and services. Innovations created in this way are introduced to the market, and if they meet customers' needs to a better degree than existing products, they take an increasing share of the market. In this way, the entrepreneur realizes an annuity from the risk incurred, while subsequent entrepreneurs (imitators/imitators) start the process of copying the solution by which the diffusion of innovations takes place. Enterprises rejecting the introduction of changes are marginalized or go bankrupt, and their assets are taken over

by companies that have accumulated sufficient funds thanks to innovation. The final stage is the introduction of another innovation by another entrepreneur, which starts the whole cycle of “creative destruction” from the beginning. Each time, the least efficient players are eliminated, so that the overall productivity driven by the most innovative companies increases. This results in economic growth.

2.3 Modern perception of Schumpeter’s theory

Schumpeter’s total output is about 30 books and more than 250 publications and reviews. They concern the shape of modern economic theory, the study of the processes of social and institutional changes of the state and economic development.

Its main tenets are:

- Cyclicity of economic development – resulting from innovative changes. Innovation is the main driver of economic development, resulting from endogenous factors. They are new products, services, production methods, new markets, new raw materials or ways of organization. They provide an opportunity to compete with innovative products, reward creativity and promote the creation of new solutions to outclass current innovations. This forces a process of invention, innovation and imitation (Schumpeter’s triad), which in turn encourages entrepreneurs in capitalism with the vision of an extraordinary annuity. It is important to distinguish between pure invention and its practical application (innovation). Only the latter has a real impact on the economy and competitiveness;
- Creative destruction – this refers to the destruction of company structures resulting from endogenous forces (innovation). It offers the possibility of above-average profit for the innovator who bears the risk, gives the opportunity for temporary monopolization and paves way for the entry of new players into the market;
- The leading role of monopolies and oligopolies (structured capitalism) attributed the main role in the process of creating innovation and economic development to corporations. These, thanks to their financial and human resources, can afford to invest heavily and take risks in research and development processes;
- The key role of entrepreneurs is characterized by “entrepreneurial spirit” and they are the most important social group from an economic perspective, as they are the ones who create innovations.

Schumpeter’s greatest contribution was seen in the study of systems dynamics. Key here was the assumption that internal factors are the ones driving the economy out of equilibrium. By this he meant that all the factors and variable parameters of a system are constantly changing, and thus he departed from the neoclassical understanding of time as a reversible parameter (Herscovici, 2023). For Schumpeter, time is historical in nature and irreversible. Nonetheless, the creation of formal models since his time has been evident, despite their irreversible arrow of time.

Schumpeter used the concepts of statics and dynamics. The dynamic theory of development gave rise to the development of research on the course of change over time – including the evolutionary view of the theory of the firm or the theories of Keynes (Maślak, 2002). The evolutionary view of the nature of economic processes assumes that change originates within the system. Like Schumpeter, contemporary economists of the evolutionary stream emphasize conceptual and formal tools for expressing complex evolutionary processes in their models (Andersen, 1995).

Although a school of economics based on Schumpeter's work did not emerge, a post-Schumpeterian current has emerged. It can include R.R. Nelson, S.G. Winter, G. Silverberg, G. Dosi, C. Freeman and N. Rosenberg. The post-Schumpeterian current is distinguished by:

- The study of economic systems is eminently dynamic in nature. They are made in terms of the changes occurring in them;
- The role of the historical approach to analyzing the emergence, development and decline of institutions is important, which is especially evident in the evolutionary literature;
- The assumption is that innovative activity triggers dynamic processes of economic change;
- In the study of competitive processes there is a division between innovators and imitators (Nelson and Winter, 1982);
- Industry competition involves innovative and imitative processes.
- Great emphasis is placed on the aspect of technology diffusion and technology imitation (Arthur, 1989);
- Methodological individualism and rejection of neoclassical assumptions of utility maximization are inevitable (Maślak, 2002).

The forerunners of the so-called Schumpeterian theory of economic growth are considered to be Phillipe Aghion and Peter Howitt, who attempted to write down the concept of creative destruction using mathematical tools. The Schumpeterian model of economic growth illustrates that the source of growth is innovation, financed by companies seeking monopolistic profit. This model highlights the dynamic in which new innovations displace obsolete technologies, resulting in creative destruction (Aghion and Howitt 2013).

In Schumpeterian models of economic growth, economic growth is closely linked to positive externalities resulting from innovation. One of the key aspects of these models is the knowledge diffusion effect, in which new, more efficient technologies replace older and less efficient ones, resulting in economy-wide technological progress. The dynamics of this progress is influenced by factors such as the stock of skilled workers and the productivity of the knowledge accumulation sphere, among others (Aghion and Howitt 1992, 2013).

Thanks to the work of Schumpeter and the post-Schumpeterian current, nowadays the role of innovation is important when developing enterprise strategies and development policies of countries and regions. It is this aspect that allows to

develop the economy and raises the economic potential of regions. In the era of digitization, innovation has become a major force driving regional development

2.4 The digital economy in terms of Schumpeterian cyclicity

The cyclical nature of economic processes in Schumpeter's theory resulted directly in the innovative activities of the entrepreneur. Entrepreneurs accumulate capital and take risks by developing innovations and implementing them in companies in search of a windfall profit (Becker and Knudsen, 2002). If successful in launching the innovation, the entrepreneur realizes a windfall profit and competitors imitate the new solution (diffusion of innovation). In this process, for additional resources, the innovator entrepreneur can take over the resources of non-innovative entrepreneurs. In this way, "creative destruction" occurs, which cleanses the market of inefficient entrepreneurs (Malerba and McKelvey, 2020).

The use of know-how and innovation as an endogenous factor lends a cyclical character to the business cycle. A company whose management takes risks and invests in creating new products and new factor combinations knocks the market out of equilibrium. As the annuity is realized, more companies imitate the innovation and some companies collapse in "creative destruction," investment slows down, and a recession ensues. This one lasts until the next innovation appears, which starts the cycle all over again (Maślak, 2002).

In this book, the authors analyze the digital economy as a high-tech IT and ICT sector along with the innovations that are digital technologies (industrial robots, artificial intelligence, blockchain, 3D printing, augmented reality, Internet of Things). The overarching innovation in this case is the emergence and rapid development of the Internet, which, along with digital data, has become the "oil of the 21st century". Their development and deployment gave the company above-average profits, which, with virtual products and full scalability on a global scale, gave birth to corporations with market capitalization comparable to some national economies.

As the digital economy matures, the threshold for entry seems to be rising. The outlays of equipment, capital and specialists needed to improve said digital technologies are making the most successful large corporations. These digital giants are forming oligopolies like the US GAFAM (Google, Apple, Facebook, Amazon, Microsoft) and China's BATX (Baidu, Alibaba, Tencent, Xiaomi). For exceptionally innovative companies that are growing rapidly, we usually see them being acquired by larger players. Examples include Facebook's purchase of WhatsApp and Instagram, Beats by Apple and Skype by Microsoft. In the quest for efficiency, we are creating digital oligopolies with extremely high economic and social power. At the same time, excessive regulation that cares about competitiveness and equality of players in the market can significantly undermine innovation, which, according to Schumpeter, finds its best environment precisely in oligopolies.

Exceptionally prominent in the digital economy is the role of the entrepreneur. The figure so glorified by Schumpeter significantly influences the dynamic digital transformation. Twentieth-century corporations hid their owners and CEOs behind

elaborate structures and a series of spokespeople. Businessmen such as Steve Jobs (Apple), Bill Gates (Microsoft), Jeff Bezos (Amazon) and Elon Musk (Tesla, SpaceX) exist in modern pop culture on a par with rock stars. The large impact on the creation of their image, dissemination of information and direct communication is due to the development of social media. However, these entrepreneurs sign their names to risky, costly and innovative activities, which are expected to radically change the market by giving them above-average returns.

2.5 Productivity in the age of digital transformation

Productivity, understood as the magnitude of the production effect obtained from given inputs, is a measure of efficiency in analyses both at the enterprise level and at the level of sectors and entire national economies. Productivity thus becomes a key factor in competitiveness. It certifies an organization's ability to use resources efficiently. In his works, M.E. Porter puts the mathematical equals sign between productivity and competitiveness (Porter, 1990). This means that an increase in productivity is desirable, because it brings with it an increase in the profitability of the enterprise and the economy as a whole (Szymanska, 2010).

The English translation of the term "productivity" also has a second, narrower meaning – labor productivity. It is the magnitude of the productive effect of a particular worker (individual), a group of workers (team) or the economy as a whole (social). Productivity is measured in terms of the number of hours worked by people employed in the economy or the number of people employed (Koziol, 2004). In the paper, the authors use both the broader category of productivity and the narrower one of labor productivity

Key in the case of labor productivity is technical progress. It makes it possible to achieve higher output with the same factor inputs or to maintain the same level of output with lower factor inputs. Thus, the effect of technical progress is an increase in labor productivity – the marginal product of labor is raised for the same level of employment. A key factor for technical progress and therefore labor productivity growth is the level of capital intensity of production. The higher it is the higher the technical armament of labor (by retrofitting factories and equipping workers with the appropriate tools and machinery), the higher the level of labor productivity. The increase in labor productivity, along with the increase in employment, affects faster economic growth.

Labor productivity through the development of technology, automation and robotization of processes is constantly being improved. The increasing technical armament of labor and the emergence of new occupations requiring higher competence is one of the effects of technological development. The role of workers is changing – they are being shifted from being direct machine operators to machine supervision and service and support processes.

This forces modern definitions of productivity to include service and non-production activities. This is especially important in the context of digital transformation. The current digital transformation is unique on many levels. Full scalability of products resulting from their intangible form is possible. Companies

that emerge in the digital economy often have no assets of their own and rely on a nexus of consumers and third parties. Examples include Airbnb, which is the world's largest "hotel" with 500 million guests annually, or Uber, which makes 1.4 billion cab rides annually. Both digital giants operate around the world using digital innovation and the sharing economy. In this way, they can serve millions of people with just 29,300 (Uber) and 14,400 (Airbnb) employees. Uber, however, does not own cabs, while Airbnb owns apartments. Both companies rely on temporary workers (gig workers) who, when providing services on their digital platform, can use their own resources while paying a percentage of their earnings to the platform owner.

A separate issue is free products. Many companies and creators offer free software, music, movies and ebooks. The very fact of their existence means that GDP accounts may be underestimated.

There is an apparent free-for-all model for many products. This model relies on funding a product through ads embedded in a movie, streaming services or phone games. Every time a user views and clicks on an ad, that's revenue. This "free" approach apparently can also mean giving away your data to the software developer. These are collected and used for Big Data analytics. In both cases, the apparent gratuitousness of products in the digital economy makes it difficult to determine their value and the dynamics of the digital economy in GDP accounts. Here, investment by companies is still the best indicator, as these are fully measurable.

All these issues make it difficult to measure the total output of the digital economy as well as its exact contribution to GDP. In turn, this makes it difficult to measure productivity (Ahmad and Schreyer, 2016).

The development of the digital economy since the 1990s has transformed more sectors of the economy, including traditional ones like agriculture. Modern and innovative solutions were supposed to support value creation, improve production and raise productivity just as they did in the three previous industrial revolutions. The question many researchers are asking is: Why haven't digital developments created a new wave of productivity growth?

Analyzing the trajectories of labor productivity presented in Figure 2.2, one can see the decreasing dynamics of labor productivity growth. The figure shows the productivity dynamics of the so-called "old EU" countries¹ from the 1970s (the industrial revolution associated with computerization) until 2017. The decline in dynamics applies to all sectors and is also present in other highly developed countries like the United States, Japan and Canada.

Academic papers recognize the so-called productivity paradox of the digital economy. Highly developed countries are experiencing a decline in the price of ICT technology, a raise in infrastructure spending and an expansion of the ICT services sector. However, these are not accompanied by productivity growth. One hypothesis is that the digital economy with its ICT technologies is still in the "installation" phase and only in the next phase of development (deployment phase) will the effects in productivity growth be observable (see Figure 2.3).

An important fact in the slowdown in total productivity growth is the simultaneous halt in the growth dynamics of the ICT sector, as well as the decline in its

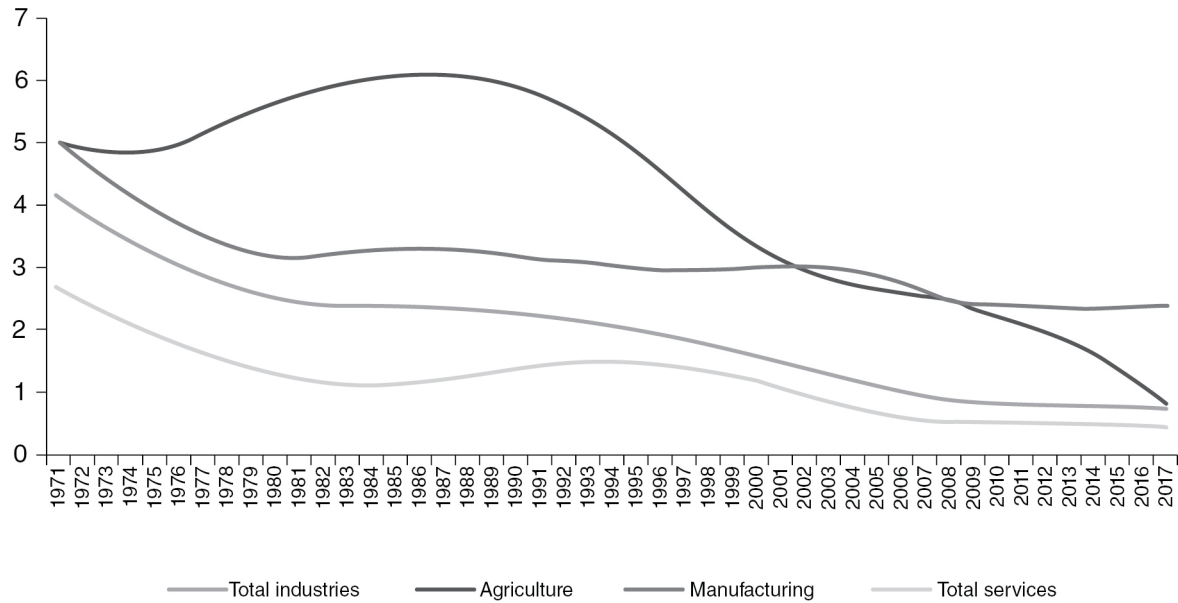


Figure 2.2 Labor productivity dynamics in selected sectors of the EU15 economy.

Source: Bauer (2020).

Note: Red – total industry; blue – agriculture; green – manufacturing; purple – total services.

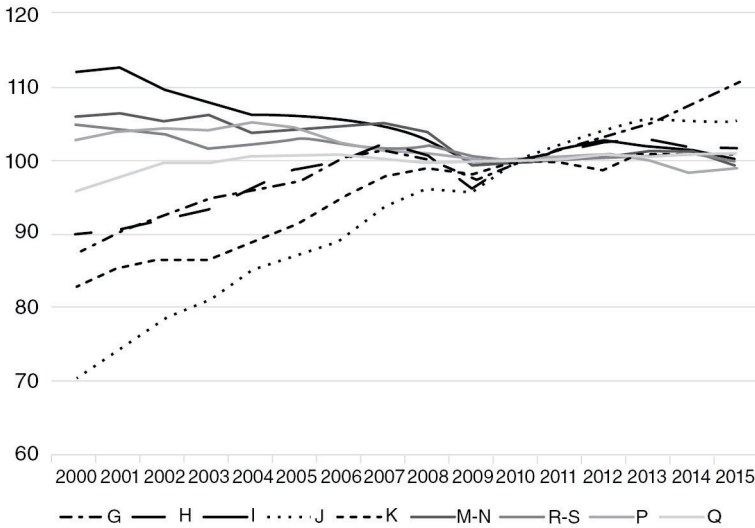


Figure 2.3 Growth rate of labor productivity in the EU28 countries in the service sector.

Note: G – trade; H – transport; I – catering; J – ICT; K – finance; M-N – professional, scientific, technical and administrative services; R-S – culture and entertainment; P – education; Q – health

Source: Bauer (2020).

importance in generating productivity growth. Figure 2.2 shows the dynamics of labor productivity growth in the European Union countries by services sector. In the 2010s, a deceleration in the growth of productivity dynamics in the ICT sector is evident, as in the others. Some – like education, professional services and culture – even decreased their productivity relative to 2010. The trade sector is the only one with increasing dynamics, which may be a signal that digital platforms and e-commerce are the first big beneficiary of digital transformation. The analysis of the labor productivity growth dynamics of the ICT and trade sectors allows us to draw interesting conclusions in relation to the first and second research hypotheses. The dynamic growth of labor productivity in the ICT sector (the core of the digital economy) has helped productivity growth in trade (the “narrow definition of the digital economy”). This can be explained by the development of virtual platforms used in e-commerce, for which the period of dynamic development occurred in the 2010s. Such an assumption, would confirm the transition to the next phase of development of the digital economy described in Chapter 1. On the basis of this, we can expect a further maturation of the digital economy, during which this effect will diffuse to other traditional sectors.

However, it should be borne in mind that the share of sectors highly saturated with digital technologies (measured in the amount of investment in ICT products and services as a share of GDP) accounted for 60% of the decline in productivity growth between 2007 and 2014 in the United States, 66% in in Germany and 54% in the United Kingdom. The share of these sectors in creating US productivity

growth fell from 46 to 26% (United States) in those years. So it is apparent that after some 20 years of generating productivity growth with digital technology purchases, their impact is being minimized. Perhaps at this point, the world is witnessing the saturation of developed economies with the necessary digital infrastructure, which would explain the shifting of investments in favor of digital services (data processing, Big Data analytics, artificial intelligence, cloud computing). A further decline in ICT prices, coupled with already adjusted laws, workforce and customers, provides an opportunity for future productivity growth. It can be based on better use of local innovation in companies, which ICT will fully transform into profits. It is necessary for businesses to understand them well, so that technologies take advantage of not only the talents of employees but also that of devices and solutions in question (Van Ark, 2016)

The so-called “learning-by-doing” is of great importance in the transition to the development phase (deployment phase). The more contacts an employee or company has with a given technology, machine or program, the more applications they find for it (Syverson, 2011). The key here is the role of experience that is currently being accumulated.

Productivity in service sectors is most often tied to the level of digital skills of employees (discussed in detail in Section 1.4). In the case of e-agriculture, which takes advantage of the achievements of digital transformation, advanced mechanization and specialization of crops and farms are necessary. Thanks to the simplification of the production chain with digital technologies, it is possible to intensify agricultural production while reducing the unit cost of goods by 19–23% (Subaeva et al., 2020). The manufacturing sector began testing industrial robots as early as the 1980s. Since then, progressive automation through CNC machines or 3D printing has increased the productivity of factories. Industrial robots are all the more productive relative to humans when the production process is more complex. ICT-based industrial production is also more efficient – by 2025, the price of industrial robots is expected to fall by 20%, while production using them means less consumption of raw materials (García de Soto et al., 2018).

At the same time, the global mining sector experienced a 3.5% annual decline in productivity in the first decade of the 21st century. This occurred despite a strong saturation with digital technologies like sensors and exploratory analysis of oil or gas deposits. In this case, it appears that mining companies are using only about 1% of the available data. It should be kept in mind that 3D modeling, robots, cyber-physical systems and augmented and virtual reality are technologies that could increase the sector’s productivity by 30% by 2025 (Durrant-Whyte et al., 2015).

Therefore, it can be assumed that the previous development based mainly on the definitional core of the digital economy (IT sector, development of selected technologies) has already reached a mature phase, and this has caused the decline of dynamic growth in productivity, wages or GDP. At the same time, the current heavy investment in the development of digital products, services and platforms on the basis of the existing ICT infrastructure (the definitional Narrow Scope) is a transitional phase in the development of the digital economy. Having reached a sufficient level of saturation with technologies (core) and products, it will be possible to

enter a dynamic period of development of the digital economy which will redefine the traditional sectors of the economy (Wide Scope). Then productivity and GDP dynamics will begin to increase as in previous industrial revolutions. Trillions of data are currently being generated in every sector of the economy, but people may not yet be able to use all of it.

2.6 The phenomenon of secular stagnation

The secular stagnation hypothesis dates back to 1938 and Alvin Hansen. He was the president of the American Economic Association. At that time, despite the end of the Great Depression of 1929–1933, the economy had not recovered to pre-collapse levels. Under such circumstances, Hansen suggested that the Great Depression ushered in an era of economic stagnation and unemployment that would be resistant to state and business action. The main causes were said to be a decline in population growth and an excess of savings over investment, which together limited the growth of global demand. The weakening propensity to invest was due to, among other things, the exhaustion of opportunities for territorial expansion, monopolization and limited opportunities for further breakthrough innovations.

The situation changed after the outbreak of World War II. A sudden increase in public spending and the post-war population boom gave a boost to demand that dismissed the specter of secular stagnation. The hypothesis of secular stagnation returned during the 2008 crisis. Demographic problems, near-zero interest rates and low inflation were cited then. It was believed that all highly developed countries would follow in the footsteps of Japan's economy, which at the time had experienced 20 years of stagnation (Mączyńska, 2015).

Summers (2013) suggested that developed countries have reached a state where the natural rate of interest (the short-term real interest rate that provides full employment) is permanently below zero. This is due to an increasing propensity to save and a decreasing propensity to invest which is holding back demand, limiting GDP growth and inflation levels. In addition, demand is hampered by a declining labor force of aging populations and the cheapness and availability of capital goods resulting from low-cost ICT technologies. This situation is forcing a change in the conduct of monetary and fiscal policy. Using conventional monetary policy, the central bank cannot reach the level of the natural interest rate even at a time of very low inflation or even deflation. On the demand side, policy reform is needed through tax cuts for the poorest, raising the minimum wage and strengthening labor unions. On the supply side, income inequality needs to be reduced, access to education needs to be made easier and through greater disposable income and social welfare, society can counteract aging (Marczewski, 2017).

However, such treatments mean in the short term the state will go into debt and expand the bureaucratic apparatus, which will also require more resources. It is possible to reduce long-term costs by developing a virtual state (e-government) and far-reaching algorithmization and automation of offices.

Piketty (2014) recognizes that growing social inequalities are an intrinsic part of the capitalist system and are discharged by revolutions, wars or deep crises.

In Central and Eastern European countries, this effect is offset and the period of dynamic growth is prolonged for two reasons. First is the “catching-up effect” – the post-communist countries started in the 1990s with low levels of productivity, income and GDP, making it possible for them to achieve dynamic growth when catching up with their rich Western neighbors. Second, the long-standing inflow of EU funds for modernization, agricultural subsidies and foreign investment provide a strong developmental stimulus which may expire when the economic level and standard of living equals that of the “old Union” countries.

In the context of the development of the digital economy, it is important to lean into changes in employment. Through so-called technological feudalism – limited social mobility with unequal distribution of wealth – workers are less able to benefit from the effects of technological development. The effects of the development of new technologies can be neutral or negative for the majority of society. Just as industrialization and mechanization in the 19th and 20th centuries changed social relations, now digitization forces constant change in employment causes instability.

Mentioned by Schumpeter is the role of structured capitalism, where giant transnational corporations create, in the form of oligopolies, the best environment for innovative activity. The effect of high and unconstrained innovation is evident among digital giants – they are among the largest companies in the world, and through monopolization, new player entry is hindered and potential contenders are eliminated or bought out.

The development of technologies such as AI, industrial robots, the Internet of Things, 3D printing or Internet services is associated with an increase in the number of patent monopolies, which limits the diffusion of innovation and postpones the positive effects of digitization on the economy. This means that monopoly companies have more resources to generate further innovations that strengthen their position. This limits competitiveness in the long term and thus limits growth momentum.

In addition, digital technologies in the fourth industrial revolution are confronting the problem of youth unemployment. In highly developed countries, despite a high percentage of employment, youth unemployment is at 14% and in countries such as Greece, Spain and Italy around 30%. This occurs despite better education and higher levels of digital skills relative to previous generations. The fourth industrial revolution tends to generate fewer jobs than it takes away as part of its creative destruction. The newly created jobs require high skills. The biggest sufferers are workers with medium skills, as they risk being relegated to a lower class by the shortage of “better” jobs (Grabowicz, 2017).

The way out is to facilitate fully flexible work in the form of a gig economy, where everyone is a contractor without attachment to an employer. To compensate for such instability, the introduction of a guaranteed basic income is increasingly being advocated. It was introduced in Spain as part of the aid package during the COVID-19 pandemic with a fixed amount given to each citizen. The amount would allow for a living and would be valorized against economic development. It would be a guarantee for the worker and facilitate flexible hiring and firing for employers.

2.7 Summary

Digital transformation and the birth of the digital economy are still evolving phenomena, which force some definitional and classification generalizations, including the concept of innovation. In Joseph Schumpeter's theory, innovations are new solutions that radically change the functioning of industries – they are responsible for economic development. After the initial idea (invention) phase, there is practical implementation (innovation) which is then copied by other companies (imitation). This is Schumpeter's triad. The leading entrepreneur in innovative activity gains above-average profits, in case of success, a temporary monopoly and the opportunity to seize the resources of non-innovative entrepreneurs through "creative destruction". Thus, on a regular basis, the market is "cleansed" of inefficient enterprises, a new distribution of resources takes place and new market opportunities are created. Thus, the cyclical nature of economic prosperity can be observed.

In the digital economy, innovations are enabled by digital technologies (Internet of Things, artificial intelligence, blockchain, 3D printing, 5G). These are endogenous drivers of higher competitiveness and thus higher profits. As in Schumpeter's theory, the creation of giant corporations (digital monopolies) is evident, which are, thanks to their resources, the most favorable environment for innovation. Companies involved in new digital technologies are the largest global companies, while their owners are a group of the richest people in the world.

However, the so-called paradox of the digital economy – a decline in the growth rate of labor productivity in highly developed countries – is apparent. This occurs despite high investment in research and development, extensive digital infrastructure and falling ICT prices, which in theory should translate into a jump in productivity growth.

Thus, on the assumption that the development of the digital economy is a creative destruction, it should stimulate an increase in the dynamics of productivity and economic growth.

However, in works addressing this topic (Gorelova, 2016; Van Ark, 2016; Syverson, 2011), the productivity paradox is apparent – as the digital economy develops, the dynamics of productivity growth and economic growth decrease. According to the authors, however, the likely reason for this condition is the continued maturation of the digital economy. Treating its current stage as a phase of installing the necessary infrastructure, it should be assumed that only in the later phase of development will a positive impact on productivity be recorded. This is supported by labor productivity data by sector, which indicate that only industries associated with the narrow and core understanding of the digital economy are experiencing dynamic growth (hypothesis three).

Another explanation for the declining dynamics of productivity and economic growth in the era of digital transformation is the phenomenon of secular stagnation. The literature (Summers, 2013) raises the concept that highly developed countries have reached a state in which the natural rate of interest (understood as the short-term real interest rate providing full employment) is permanently negative. This is due to an aging population, growing social inequality and declining innovation.

An increasing share of income is held by the wealthiest groups with a higher propensity to save. As the population grows older, uncertainties about the stability of the pension system increase, prompting people to accumulate funds on their own for old age. Together, these factors cause the rates of investment and consumption to fall, aggregate demand is inhibited and GDP growth becomes limited. Treating interest rates as the price of capital, it should be assumed that excessively rising savings reduce natural interest rates. A factor that intensifies this process is the expectation of further stagnation present in the market. This leads to a situation where the central bank is unable to catch up with the natural rate of interest with its monetary policy and thus lacks stimulation of investment in the economy.

Note

- 1 Old EU countries are countries that joined the European Union before 2004. Countries that joined the EU after 2004 are referred to in this book as countries of the New Union.

3 Dimensions of the digital economy

3.1 Introduction

Digital transformation is based on the development of the Internet and digital technologies. They are the ones that have enabled the creation of new digital products, virtual distribution and the emergence of new businesses and entire industries. ICT technologies, in successive generations, have offered an ever-increasing range of functionality while at the same time becoming cheaper and cheaper, leading to their widespread adoption.

The division of the digital economy into three levels, mentioned in Chapter 1, shows the cascade of digital transformation:

- Core – this is the first stage when the IT and ICT sectors, thanks to technologies such as 5G, 3D printing, blockchain and the Internet of Things, introduces new telecommunications and data processing products;
- Narrow in scope – digital platforms, sharing economy and digital services are emerging. Behind them are emerging giants with new business models (including Uber, Google, Facebook, Airbnb, Amazon). Here, technologies from the previous level are creating new processes, transforming distribution and changing economic issues like usability and ownership;
- Broad scope – the third stage is the diffusion of digital innovations beyond the technology industry into all sectors of the economy;

The purpose of Chapter 3 is to capture the broad definitional scope of the digital economy. It discusses developments in:

- Agriculture, where the use of advanced ICT technologies makes it possible to optimize yields and conduct precision agriculture;
- Industry, where the fourth industrial revolution, based on virtualization and the Internet, is changing the face of industrial production by betting on robotization, autonomization and smart factories;
- Commerce, which takes advantage of the opportunities arising from virtual transactions, creates virtual stores and marketplaces to be open 24/7 to customers

from all over the world, generating more and more revenue and responding to the current needs of consumers;

- Finance, where digital technologies have led to the emergence of entirely new entities with less “mass” and greater flexibility by which they (fintechs) have challenged traditional banking by competing for the customer with higher levels of convenience of use and lower prices;
- A labor market that is forcing workers to possess digital skills at increasingly higher levels and is transforming from statist to contractual and extremely flexible (gig economy);
- Public administration, which wants to reach out to citizens by offering them access to documents, medical services or cultural goods via the Internet. At the same time, protecting the security of citizens and their data in cyberspace.

3.2 E-agriculture and Industry 4.0

The development of ICT in agriculture has led to improved rural development and more efficient crop and animal husbandry. Technological advances have made it possible to provide farmers with accurate and timely information and services, creating room for more profitable digital agriculture (e-agriculture). E-agriculture involves the conceptualization, design, development, evaluation and application of innovative uses of ICT in rural areas (Mahant et al., 2012).

E-agriculture is a relatively new concept, so its scope will evolve over time. For this reason, in 2008 the UN described it as an emerging industry (Mangstl, 2008). The projected human population will exceed 9 billion in 2050. This means that agricultural production will need to increase by 60% from current levels. To meet this, the agricultural sector has begun to invest in modern technologies to increase production and enhance competitiveness. The main roles of ICT application in agriculture are (FAO, 2017):

- Promoting sustainable farming methods;
- Use of natural disaster warning systems that minimize the risk of crop losses;
- Accessing global markets and connecting consumers and producers;
- Access to financial services for agricultural areas (securing savings, insurance and risk management tools);
- Connecting farmers and researchers in related fields and creating opportunities for women and youth in agricultural areas.

Digital agriculture encompasses a wide range of technologies, most of which have multiple applications in the fetching value chain. These include (Sylveter, 2019):

- Computers and websites – providing access to market information;
- Internet, 5G and mobile telephony – sharing knowledge and experience, creating agriculture-centered communities, accessing accurate real-time weather forecasts, developing banking and trading platforms;

- Big Data analytics – provides analysis of data from devices, sensors and weather conditions important to precision agriculture;
- Guidance and tracking systems (GPS, GNSS, RFID) – systems allow animals to be identified through chips, track changes in animal location and health, analyze the location of machinery and autonomize the operation of vehicles;
- Advanced machines – robots and autonomous vehicles (ground and aerial drones) provide further automation of work increasing productivity;
- The Internet of Things – a network of sensors in agricultural machinery allows for information in real time that allows for better and more efficient decision-making.

As a result, digital technologies make it possible to conduct precision, or computer-assisted, agriculture. Collected data (from agricultural machinery, the location of machinery supported by satellite positioning [GPS], analysis of weather and soil conditions) allow accurate planning of fertilization, plant protection against pests, storms or droughts and ultimately increase yields, improving their quality and reducing production costs (Gozdowski, Samborski and Sioma, 2007).

For this reason, the EU has earmarked more than €200 million under the Horizon 2020 framework program to develop innovation through the deployment of digital technologies in the agricultural sector; €75 million has been earmarked for robotics; and €80 million for the deployment of the Internet of Things and digital platforms (European Commission, 2021a). This is intended to help counteract roadblocks facing digital agriculture such as poor communication infrastructure, lack of awareness of the benefits of digitizing livestock and crops, lack of digital skills among farmers and reluctance to share data.

All these activities translate into the development of e-agriculture worldwide. By 2025, the value of the precision agriculture sector will reach \$2.5 billion, field monitoring \$2.3 billion, precision fertilization \$1.2 billion and precision planting \$1 billion (European Commission, 2021a).

The fourth industrial revolution, described in Sections 1.2 and 1.3, together with the development of digital technologies, led to the creation of the concept of Industry 4.0. It consists of developed industrial robotics, artificial intelligence, Big Data analytics, cloud computing, 3D printing, Internet of Things or augmented reality (Kagermann et al., 2013). The term “Industry 4.0” itself was first used by the German government in the context of the German manufacturing sector’s digitization strategy (BMBF, 2013).

Among the forces triggering industrial change are social, economic and political issues such as (Lasi et al., 2014):

- Short development periods – pressure to shorten innovation development time. The key to success for companies is becoming high innovation, which allows rapid implementation of new solutions in the market;
- On-demand individualization – the shift from a seller’s market to a buyer’s market that has been going on for decades due to market saturation is evident

here. Buyers want to determine the terms of trade which forces individualization of production;

- Flexibility – increasing flexibility in product development and production process;
- Decentralization – a flattened organizational hierarchy allows for faster decision-making processes that respond to dynamic market fluctuations;
- Efficient management of resources – scarcity of resources causes their prices to rise. Therefore, there is a growing need to take care of ecological aspects, making production move towards a sustainable industrial model.

The main catalyst for the outbreak of the fourth industrial revolution was the development of the Internet. It enabled global and instantaneous communication between humans, as well as between humans and machines by means of cyber-physical systems (CPS). The introduction of the concept of Industry 4.0 is no accident. The German economy derives 25% of its output from the manufacturing sector, employing more than 7 million workers (about 16% of the workforce) (Brettel et al., 2014).

CPS are transformational technologies dedicated to managing interconnected systems between their physical resources and computing capabilities. Technological developments have increased the availability of sensors, data management systems and computer networks making it necessary for today's industrial plants to implement advanced technologies to remain competitive. The increased use of sensors as part of the Internet of Things has led to the creation of large data sets (Big Data). CPS manages these collections with algorithms and uses interconnected machines to make them an intelligent and self-adapting organism. CPS integrates manufacturing, logistics and services to improve equipment efficiency and product reliability and quality. Transforming traditional factories into Industry 4.0 factories (smart factories) raises economic potential. By 2025, the German economy will gain a total of 267 billion euros thanks to Industry 4.0 (Lee, Bagheri and Kao, 2015).

CPS systems are also changing the way workers interact with machines (Operator 4.0). The use of industrial exoskeletons – portable devices worn by workers, equipped with hydraulic actuators and a set of motors – significantly increases their endurance and strength and enables them to work in harsh conditions. They are used in warehouses, as well as in hospitals (supporting nurses in caring for patients) and even on battlefields (where soldiers gain greater lifting capacity and reach). Supporting workers with augmented and virtual reality equipment – VR goggles, smartphones, projectors – allows for better training, more accurate machine operation and remote work (especially in high-risk areas) (Romero et al., 2016).

The European Union in 2020 laid the groundwork for an EU industrial strategy. Its aim was to raise the global competitiveness of European industry, increasing autonomy, resilience and innovation. At the same time, production growth is to be linked to achieving climate neutrality, which also provides an innovation stimulus for companies (e.g., zero-carbon steel or energy production). In terms of autonomy, strategic areas where the EU is dependent on external players are raw materials, batteries, pharmaceutical ingredients, hydrogen, semiconductors,

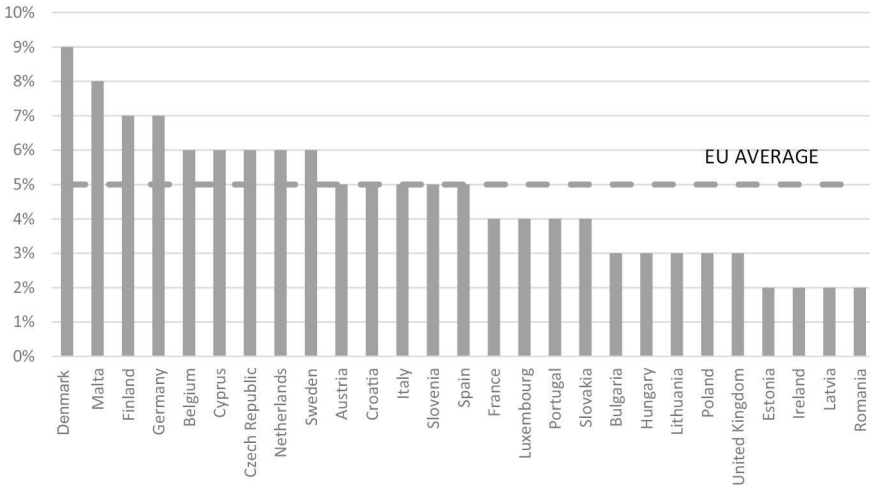


Figure 3.1 Share of companies using 3D printing in 2020.

Source: Eurostat (2023); Database: ISOC_EB_P3D.

cloud technologies and advanced technologies (European Commission, 2021b) (see Figure 3.1).

The figure proves the level of development of Industry 4.0 within the European Union. Looking through the prism of market adoption of additive (3D) printing among European companies, one can see the leaders (Denmark, Malta, Finland, Germany) outpacing even four times the last countries on the list (Estonia, Ireland, Latvia, Romania). Poland ranks below the EU average (at 5%) with 3% of companies using 3D printing.

3.3 E-commerce and digital services

The development of the Internet has made it possible to provide services digitally. Automated services can be provided remotely and with minimal human intervention. The time of day or geographical location is not important. Through the Internet, mobile devices (smartphones, tablets) or satellite TV, it is possible to access entertainment (music, movies, games), gain education (through remote teaching, websites, magazines, ebooks), enable communication (video calls, chat rooms, forums, social media), engage in physical activity (exercising online with a trainer) and even maintain regular employment (call centers, consulting, freelancing, financial services). Especially during the COVID-19 pandemic and lockdowns, investment in developed distribution networks for digital services has become crucial. The most important areas of digital services are as follows (Flis et al., 2009):

- E-health – the ability to remotely consult a doctor, register for an appointment at a facility or pick up a prescription;

- E-work – the use of the Internet enables remote employee recruitment, cooperation, project execution and access to company data resources;
- E-learning – these are language courses, professional training, higher education and remote school lessons, tutoring and electronic textbooks;
- E-logistics – these are services that support the supply chain, coordination of drivers and business partners and real-time map tracking of specific shipments and packages;
- E-finance – the ability to conduct all financial, banking, investment and insurance activities using dedicated software and Internet access;
- E-commerce – trading via the Internet, discussed in more detail further in subsections;
- E-government – the provision of public services through ICT technology. It is the ability to submit applications to offices and letters electronically and even conduct a popular vote over the Internet;
- E-culture – access to scanned images and cultural works in digital form (including through augmented and virtual reality). This facilitates cultural access for people with disabilities or those living in rural areas.

The digitization of the economy is entailing far-reaching changes in commerce. Traditional markets and bazaars are moving into the virtual realm as e-commerce (electronic commerce). E-commerce, in short, is the selling and buying of products and services via computer networks (OECD, 2013). It implies a change in the form of seller-buyer communication processes, sales, order and payment processing, marketing and logistics. Computer networks are becoming the place where business information is shared, relationships are maintained and transactions are conducted digitally (Zwass, 1996). E-commerce and Industry 4.0 intermingle and complement each other. The use of the Internet of Things, augmented reality and Big Data allows for better personalization of the advertising message and production process, automating the value chain, reducing costs and improving customers' shopping experience (Zagajewski and Saniuk, 2018).

The growth of e-commerce is being stimulated by an increase in the number of people with Internet access due to the declining cost of Internet connectivity, the development of Internet portals, a developed cell phone market and greater awareness of e-business. All these factors show the acceptance of the increasing purchases conducted over the Internet. Barriers to the development of e-commerce are legal and tax restrictions and their inadequacy to meet market needs, language barriers and lack of reliable security systems. However, the biggest barriers are the inadequate level of development of telecommunications networks in selected regions and the low level of digital skills (Wawarczyk, 2003). In order to develop e-commerce, the European Union in 2015 began work on the EU Digital Single Market. The main goals are to increase the availability of digital services, raise the level of digital skills, create an enabling institutional environment and maximize the potential for the development of the European digital economy (Szymanowski, 2016).

To reconcile both skeptics and advocates of e-commerce, companies are pursuing simultaneous omnichannel commerce. In such a model, the boundaries

between online and offline shopping are blurred, making all channels of distribution and customer contact interconnected. The seller gives buyers a consistent shopping experience, which in Europe results in 15–30% more purchases made by customers (Pieczarka, 2020) (see Table 3.1).

Table 3.1 Summary of characteristics that differentiate forms of trade

<i>Sphere</i>	<i>Traditional trade</i>	<i>E-commerce</i>
Marketing and advertising	<ul style="list-style-type: none"> • It is based on traditional media (television, radio, press) • High cost of acquiring and processing data • Obsolescence due to time consumption 	<ul style="list-style-type: none"> • It uses online marketing mechanisms (social media, content marketing, influencer marketing, newsletters, YouTube, Google AdWords) • Gain information about current and potential customers in real time (using Big Data)
Sales strategy Forms of communication	<ul style="list-style-type: none"> • Product focus • Face-to-face communication. • Communication through intermediaries • Sending physical documents by mail • Phone contact 	<ul style="list-style-type: none"> • Customer focus • Communication via the Internet (screen to face) • Usage <ul style="list-style-type: none"> ◦ Email ◦ Websites ◦ Mobile applications
Forms of payment	<ul style="list-style-type: none"> • Cash • Payment card • Check 	<ul style="list-style-type: none"> • Payment card • Bank transfer • Electronic payments • SMS/phone micropayments • Payment upon receipt of goods
Availability	<ul style="list-style-type: none"> • Specific opening days and hours (e.g., Monday through Friday) • Order placed at a specific location 	<ul style="list-style-type: none"> • Conducting transactions around the clock (24/7) • Order placed anywhere
Delivery parameters	<ul style="list-style-type: none"> • Goods collected immediately or delivered for a fee to the indicated location 	<ul style="list-style-type: none"> • Goods delivered electronically (digital products like ebooks), by courier or by mail
Market participants	<ul style="list-style-type: none"> • Manufacturers • Consumers • Intermediaries 	<ul style="list-style-type: none"> • Manufacturers • Internet users • Intermediaries
Customer contact	<ul style="list-style-type: none"> • Physical and visual • Formalized information flow between the customer and the company 	<ul style="list-style-type: none"> • Multimedia and remote • Prompt and interactive advice and assistance • Automated information flow
Relationships	<ul style="list-style-type: none"> • Interpersonal 	<ul style="list-style-type: none"> • Virtual

Source: Pieczarka (2020).

The European e-commerce market is now entering a mature phase of development, which translates into increasingly widespread online shopping and a lower growth rate (15% on average per year, compared to the global average of 21% over the last decade). Around 87% of Europeans use e-commerce at least once a year, which translates into an annual spending of €717 billion. The largest markets are Germany (61 million e-commerce customers) and the United Kingdom (49 million). The largest turnovers were in Germany (€62.8 billion), the United Kingdom (€52.4 billion), France (€38.3 billion), Spain (€34.1 billion), Italy (€32.4 billion), Poland (€13.9 billion) and the Netherlands (€12.8 billion) (Postnord, 2020).

In terms of market adoption in European Union countries, 71% of the population used online shopping in 2020. The leader is the United Kingdom, Denmark, Sweden and Germany. In addition, the only countries in the “New Union”¹ that achieved a result above the EU average are Estonia and the Czech Republic. Among the countries with weaker e-commerce uptake, we find mainly Central and Eastern European countries, with the exceptions of Italy and Portugal (see Figure 3.2).

The Polish e-commerce market includes 28.2 million users (85% of the population aged 7–75 years old). Around 72% of them use online shopping and 30% use foreign online stores. The most common products purchased in Poland are clothing, footwear and cosmetics. Polish customers use laptops (80%), smartphones (69%), desktops (50%), tablets (24%) and e-book readers (1%) for online shopping. The main incentives for customers are the ability to order goods 24 hours a day (no need to drive to a store), the possibility of unlimited time to choose and compare products and to seek opinions and reviews about them. A decisive argument for

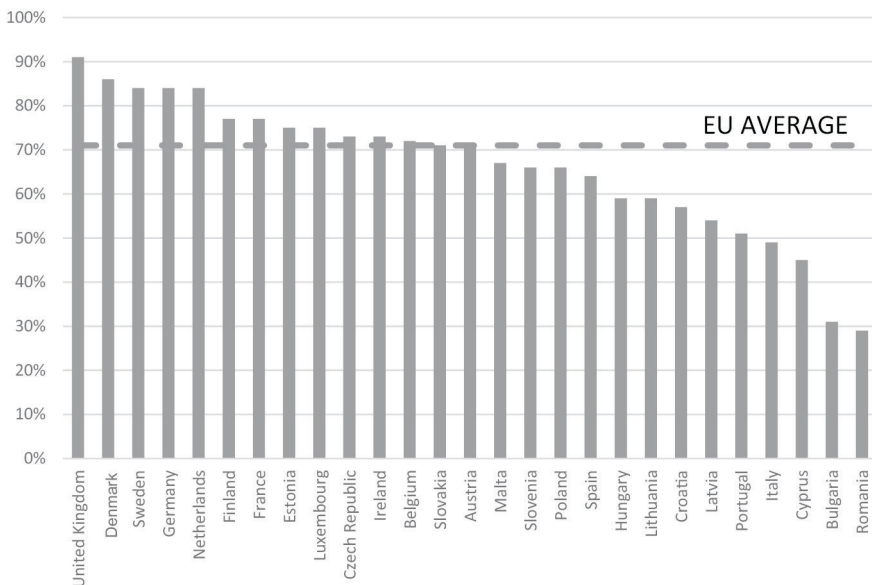


Figure 3.2 Share of people using e-commerce in 2020.

Source: Eurostat (2023); Database: TIN00096.

choosing a particular store is positive user reviews, transparent methods of delivery and product complaints and clear descriptions of goods. These factors mean that, despite the lack of opportunity to physically “test” the goods before purchase, the customer is more certain of satisfaction of the purchase (Gemius, 2020).

3.4 Fintech and open-banking

In the course of technological development, the financial industry has undergone a revolution. As a result of the computerization and digitization of financial services, a new sector called fintech (from the combination of the words “finance” and “technology”) has emerged. The fintech sector, in terms of entities, includes those originating from the technology industry. They possess the necessary know-how and technical facilities with which they offer innovative financial products. In this narrow view, the fintech sector can only include new technology companies with a high degree of flexibility, innovation and a focus on the competitive advantage over traditional banks that technology provides. In a broader view, the fintech sector can also include digital giants offering financial services and even traditional banks investing in digital solutions (Harasim and Mitreġa-Nieštrój, 2018).

Historically, the origins of fintech can be traced back to the late 1990s. Thanks to the advent of the Internet, the era of electronic banking emerges and the first online banks appear. They are distinguished by the absence of physical outlets and fully remote customer service. The first fintechs in the full sense of the word appeared at the beginning of the 21st century as small entities cooperating with banks to facilitate customer access to financial services. In the second decade of the 21st century, mobile banking and apps emerged thanks to the “*smartphone revolution*”, and banks’ attitudes toward fintechs changed. Some banks tried to acquire financial start-ups, while others created gas pedals to partner with them and benefit from their flexibility and innovation. Currently, one can observe the third stage of development (fintech 3.0), where traditional banks want to become fintechs, fintechs gaining banking licenses become neobanks and digital giants from the GAFAM group (Google, Apple, Facebook, Amazon, Microsoft) enter the market (Szpringer, 2019).

By definition, fintech is a highly innovative sector, and its main weapons in the competitive struggle are new technologies such as the following (PWC, 2017) :

- Development of solutions for mobile devices;
- Advanced data analytics (Big Data);
- Development of artificial intelligence (algorithms, neural networks, machine learning);
- Cyber security;
- Robotization and automation of processes;
- Biometrics and identity identification;
- Blockchain.

The range of influence of fintechs seen in Table 3.2 shows that they are working to modernize almost all areas of finance. One can find companies engaged in

Table 3.2 Classification of the object scope of fintech sector activities

<i>Deposit and credit services</i>	<i>Payments, clearing and settlement services</i>		<i>Investment management services</i>
	<i>Retail</i>	<i>Wholesale</i>	
<i>Crowdfunding</i>			<i>High-frequency trading</i>
Lending platforms	Mobile wallets	Alternative remittance networks	Copying transactions
Mobile banking	Payments peer-to-peer	Foreign exchange services for companies	Internet trading platforms
Credit scoring	Cryptocurrencies	Cryptocurrency trading platforms	Robo-advisory

Source: Harasim and Mitręga-Niestrój (2018).

investment management, fundraising or deposit services. The largest number of players are engaged in payment services. This requires specialized employees with knowledge of finance, econometrics, computer science and robotics.

There are six visible regions in Europe that concentrate on fintech start-ups, creating a favorable environment for the development of digital businesses. The main determinants of fintech development in these places are the presence of headquarters of large banks and companies, incubators and gas pedals for start-ups and legal and fiscal facilitation (Gazel, 2018). The fintech clusters in Europe are (European Commission, 2015):

- North Holland (the Netherlands);
- Düsseldorf (Germany);
- Île de France (France);
- Berlin (Germany);
- Inner London (United Kingdom);
- Upper Bavaria (Germany).

Among the impacts of the digital transformation in finance, the shift away from physical branches to remote service is evident. In Poland alone, banking employment was reduced by 19,000 full-time positions between 2008 and 2018. Modern banking operations are based on three trends (Korenik, 2006):

- Multichannel banking – investing in different distribution channels (mainly digital) along with reorganizing existing ones (e.g., co-working spaces in bank branches);
- Self-banking/Mobile banking – a formula according to which the customer independently makes deposits, opens deposits and accounts and performs transactions. Most actions are possible from the mobile application;
- Allfinanz/bancassurance – selling products in packages, which are constructed from a combination of profitable and loss-making products for the bank or insurer; thus, it is possible to reduce prices, simplify the range of services and increase sales.

Fintechs have understood that the main constraint to growth is the issue of security. It is the certainty of safe entrustment of one's money and trust that determines that people trust traditional banks when depositing their savings in accounts. For this reason, more fintechs began to apply for a banking license. This gave them deposit guarantees for their customers and they became neobanks (in. Challenger banks). At the same time, they were developing their computer systems, streamlining data turnover and order execution, so that the user experience of their services (user experience) was rated higher than that of traditional banking. Their main advantages over traditional banks are (Gorka, 2018):

- Low operating costs (fully digital operations with no physical branches);
- Serving young people through mobile access to services;
- Scalability of the business thanks to APIs (using someone else's infrastructure);
- Lower prices thanks to new technologies, optimization and a low C/I ratio;
- Flexibility and rapid adaptation of new technical solutions;
- Simple offer and price list construction and self-service inside the application, which further reduce costs.

The mutual coexistence of traditional banking and fintech has led to the concept of open banking. Open banking is based on financial services that utilize APIs. An open API is a set of standardized functions and procedures that give users of other applications the ability to access data in one entity. This increases functionality for the application user. In addition, customer satisfaction increase and new opportunities for distribution and development of innovations emerge. The biggest challenge here is to provide secure connections to customer systems and ensure a high level of privacy.

A big boost to the development of the European fintech market was the introduction of the Payment Services Directive 2 (PSD2) implemented in 2016 by the European Parliament. It requires the banking sector to make changes on a legal, technological and strategic level. It forced the provision of an API standard by financial entities, increased transaction security and the creation of so-called open banking. Third parties can have encrypted access to a customer's payment data at other banks, initiate payments and check transaction history and bank account balances. The implementation of the directive was accompanied by resistance from banks, as it was on them to bear the cost of maintaining the infrastructure while external smaller companies (fintechs) would have free access so there would be a kind of free-rider effect (Grzywacz and Jagodzińska-Komar, 2018).

A big facilitator of the development of open banking and fintech is the willing use of online banking including mobile banking. On average, 58% of Europeans handle their bank account online. In Scandinavian countries, the Netherlands or Estonia, this exceeds 80%. This provides an opportunity for a much stronger reduction in physical outlets, a focus on mobile channels and competition between fintechs and traditional banks. Slower changes will occur in countries like Poland, Romania and Italy, where the smaller number of online customers still forces the maintenance of a large branch network and a slower transition to an *Internet only* model (see Figure 3.3).

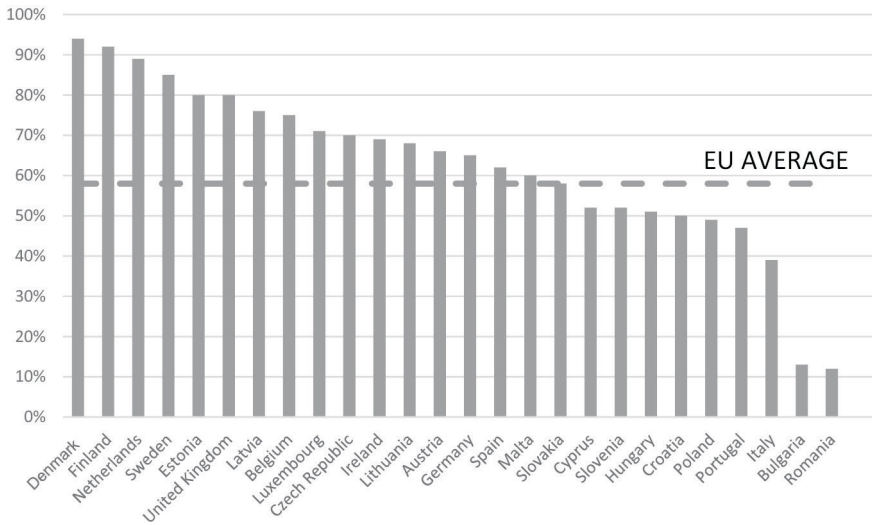


Figure 3.3 Share of population using online banking in 2020.

Source: Eurostat (2023). Database: ISOC_BDE15CBC\$DEFAULTVIEW.

In Europe, the number of fintech players reaches 3482. The main countries of origin are: the United Kingdom (44%), Germany (8%), Spain (6%), France (6%), Switzerland (5%) and the Netherlands (5%). The main areas of activity are payments and accounting services. In turn, the fastest growing is the cryptocurrency industry (Deloitte, 2020). European neobanks include: Revoluta (United Kingdom), Starling Bank (United Kingdom), Monzo (United Kingdom), Atom Bank (United Kingdom), n26 (Germany) and bunq (the Netherlands).

3.5 Gig economy – a new job market

The development of the Internet, communication technologies and digital platforms has led to far-reaching changes in the labor market. Here, the main change is the increased freedom in the conclusion and termination of contracts between employee and employer (Eurofound, 2015). The process intensified after the 2008 financial crisis, when people en masse wanted to at least partially participate in the labor market and earn an income. The growing market for nonstandard forms of employment and labor relations led to the birth of the gig economy.

“Gig” refers to short-term arrangements typical of a musical event. A fledgling musician may celebrate by performing a single performance in a pub or other venue. A single performance does not guarantee that musician regular performs. The chance of a repeat gig increases when the musician plays exceptionally well or becomes popular. He or she may receive payment either in the form of a fixed fee per performance, a share of ticket profits or in the form of barter (free drinks, food, etc.). Costs associated with the performance (purchase of instruments, travel, costumes) may or may not be covered by the organizer. The newly coined term

“gig economy” does not yet have a solidified Polish version, but the term “concert economy” allows us to understand its essence – uncertainty in flexibility (Woodcock and Graham, 2020).

Another version of the translation of “gig economy”, is the on-demand economy. This concept is gaining popularity in Anglo-Saxon countries because of the flexibility of access to workers depending on production needs. A person who is a workforce, in this model, offers to perform tasks for different people and organizations as part of their working life. The range of services is extremely wide – from graphic design, copywriting, transportation of people and goods to cleaning. It is important to correctly define who participates in the gig economy. Some researchers also include freelancers such as artists, journalists, writers, contract managers and freelancers in the term. However, in order to better understand the phenomenon of the “gig economy”, two terms need to be defined (De Stefano, 2016):

- Crowdwork – refers to collective labor. It is a form of employment where, through digital platforms, principals advertise the need for a service, task or solution to a problem in exchange for a specific payment. The platform allows the principal to access a large group of potential employees. This form makes it easy to delegate simple and single tasks (micro-tasks) to virtual employees, such as research, filling out surveys or designing a logo or application.
- On-demand work – here, too, digital platforms play first fiddle. The term refers to tasks in the field of transportation, cleaning, repair or delivery of goods. Well-known applications that enable on-demand work are: Uber (car transportation), Fixly (construction services, gardening, small repairs), Fiver (video processing, graphic design, text writing, application creation).

New technologies have made it possible to hire workers only when necessary, only when the company has a shortage of hands and sometimes even without a guarantee of payment of wages (zero-hour contract). This is because, in extreme cases, the worker has no framework for a minimum or maximum number of working hours per month. It can be zero or forced self-employment. The service contractor gets paid only when he is needed by which there is no financial stability. This raises the biggest problem of the gig economy – lack of labor rights. In many cases, the licensing agreement of an app or online platform does not say “job” or “employee” but “service” and “task”. This means that an intermediary company like Uber does not have to provide the employee benefits it would be obligated to if it were a traditional transportation company. The moment a driver has no runs, he gets nothing. This is leading to numerous protests and an increasing number of lawsuits. It is likely that in the near future organizations will be formed to protect the rights of workers in an era of an extremely flexible labor market (Kowalik, 2017). Another possible response to the changing labor market and lack of attachment to the employer may be an unconditional basic income, which addresses the issue of meeting basic needs. In such a model, work is a privilege and not an obligation, as is salary (see Figure 3.4).

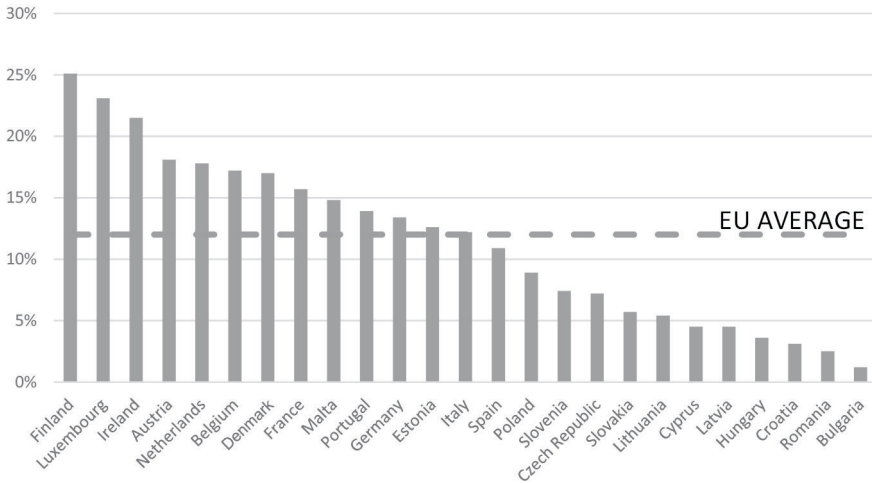


Figure 3.4 Number of people working remotely as a % of the workforce in 2020.

Source: Eurostat (2023); Database: LFSA_EHOMP\$DEFAULTVIEW.

There is also a noticeable trend in the development of telework (remote work). White-collar workers in highly developed countries are increasingly performing their duties for their employer without leaving home. They use company computers, cloud solutions and high-speed Internet. Between 2012 and 2020, the number of people doing remote work increased from 5.5% to 12%. A strong driver here was the COVID-19 pandemic. However, the savings and flexibility derived from it will likely remain in the labor market even after the pandemic. The leaders in remote work are the “old EU” countries, with high innovation and the largest share of the service sector in employment (Finland, Luxembourg, Ireland) (see Figure 3.5).

Increasing digitization means that already 35% of Americans are *freelancers*. It is estimated that by 2027, the number will also rise to 50% (Morgan Stanley, 2018). At the same time, the number of people performing their work duties remotely (telecommuting) is growing, and the COVID-19 pandemic has compounded this phenomenon. In the European Union, 4.8% of the workforce was working remotely in 2014, and by 2020 it was already 12% (Eurostat). All of this means the need for a computer, smartphone and internet access (Rozkrut, 2018). However, in order to fully participate in the digital information society; it is necessary to have a minimum of basic digital competencies such as (Klimczuk et al., 2015):

- Education – gaining new skills, e-learning, sharing knowledge with others;
- Everyday matters – doing official business online, shopping online, planning travel and transit;
- Finance – manage your finances, compare prices, earn money through online jobs;

Employment specialisation, 2016

(percentage points, based on difference compared with EU-28 average, by NUTS 2 regions)

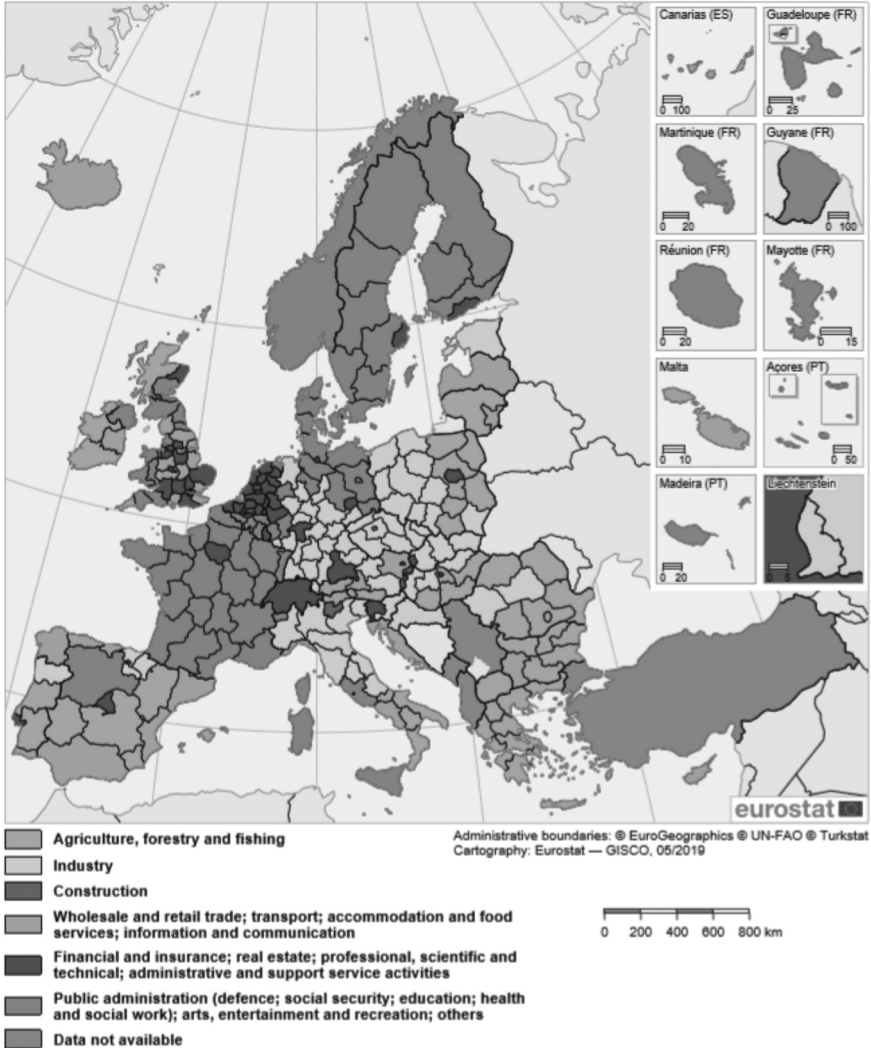


Figure 3.5 Dominant specialization in EU countries at NUTS2 level in 2016.

Source: Eurostat (2021).

- Relationships with loved ones – maintaining social and family relationships at a distance, taking care of privacy, managing information about oneself and image, parental control;
- Work and professional development – the ability to find a job, improve skills, run a business, hire employees;

- Health – leading a healthy lifestyle, using healthcare, checking medical sites;
- Leisure and hobbies – finding online people with similar interests, being able to find websites on interesting topics, taking care of personal development;
- Civic engagement – using the services of municipal offices, cultural centers, NGOs or using a certified electronic signature;
- Religion – knowledge of sites on spiritual and religious development, participation in forums and communities.

The lack of these skills leads to the phenomenon of digital exclusion. This is the result of a lack of skills in using civilization's technological achievements. This causes social stratification into those who have computers with Internet access and those who have limited or negligible access to the network. It is worth adding that in addition to the physical lack of access to technological achievements, it is possible that there is a lack of desire to use it (digital self-exclusion). As a result of stratification, three social classes have emerged:

- *Digital proletarians* – people without access to computers and books, while addicted to television and audiovisual broadcasting;
- *Digital petty bourgeoisie* – people who passively use computers;
- *Digital nobility* – people who are able to use the computer to perform analysis and can distinguish valuable information on the Internet from that which contributes nothing.

Individuals particularly vulnerable to this phenomenon are the elderly (who grew up without computers), the disabled and the poor. For them, a lack of digital skills and access to technology means an inability to maintain social relationships, hold gainful employment or handle administrative matters. Their perception of society is thus greatly reduced (Garwol, 2019) (see Figure 3.6).

Countries with low percentages of digital literacy (both primary and secondary) are the most vulnerable. These include: Bulgaria, Romania, Italy, Latvia and Poland. They score well below the EU average of 58%, which hinders the development of digital public services, open banking or e-commerce.

3.6 Algorithm economy – the new face of state administration

The PWN *Dictionary of the Polish Language* provides the definition of an algorithm as a “rule of conduct leading to the solution of an established problem, specifying a sequence of elementary actions to be performed for this purpose” (PWN *Dictionary of the Polish Language*, 2021). The digitization of the economy is based on the algorithmization of all economic processes. The corresponding amount of data is generated by machines (Internet of Things) and people (e-commerce consumers and Internet users). Large data sets (Big Data) are managed by artificial intelligence, whose behavior is dictated by algorithms.

An ordered sequence called an algorithm allows for the creation of more perfect products and the replacement of humans in increasingly creative professions

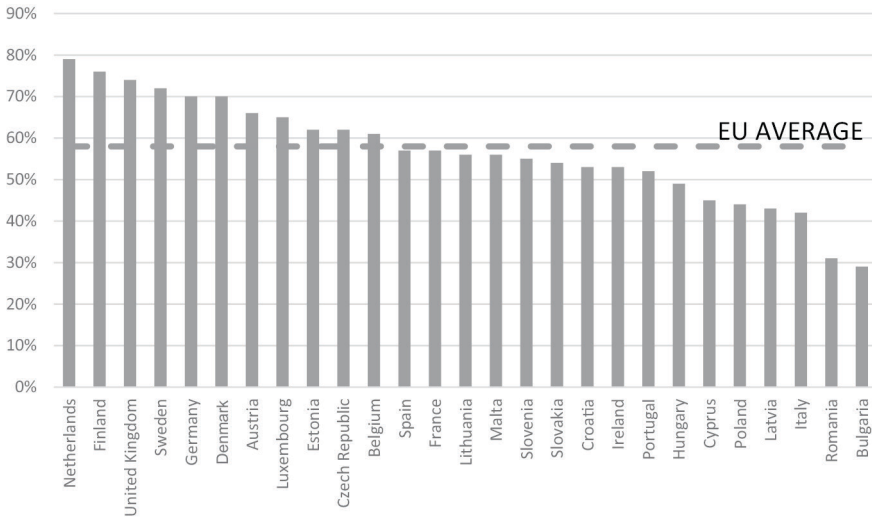


Figure 3.6 Share of people with basic and secondary digital skills in 2019.

Source: Eurostat (2023); Database: TEPSR_SP410.

(such as writer, lawyer, salesman or stockbroker). An algorithm makes it possible to predict the behavior of weather, financial markets and communities. Algorithms assess the risk and credibility of a borrower, and since they are based on data rather than emotion they are attributed greater arbitrariness and their judgments and decisions greater fairness. This raises concerns about potential judge algorithms, as the programs tested so far have proven imperfect. A British university's admissions system discriminated against women and people from India and Pakistan, while an appeals program in the US judiciary treated blacks worse than whites for the same crimes. This means that despite technological development and the increasing reliance on algorithms and artificial intelligence, its implementation into the economy and social life must be subject to close scrutiny (Mamak-Zdanecka et al., 2019). Even the term algorithm economy has been coined in reference to the exchange, commercialization and distribution of algorithm code between programmers which increases innovation and allows faster commercialization of scientific research (Gartner, 2016).

When it comes to regulating cutting-edge products and technologies (such as artificial intelligence and fintechs), one solution may be a regulatory sandbox. Owing to the fact that the financial sector cannot conduct experiments directly on the market, it has been recognized that technological and financial innovations should be tested under the guidance of market regulators in a safe manner. This supports the development of financial start-ups, shortens the time to market, improves access to funding for innovations and promotes adequate consumer protection. Companies in the sandbox do not have to acquire complex and expensive licenses. The first regulatory sandbox was established in 2015 in the United Kingdom thanks to the

local regulator (Financial Conduct Authority [FCA]). Companies selected through a staged call had to meet conditions as to the innovation and scope of implementation, after which they could get approval to test the product. It has been observed in subsequent years that similar regulatory sandboxes have been opened around the world, which have increased innovation, reduced barriers to entry and shortened the time to obtain the relevant licenses (Marchewka-Bartkowiak, 2019).

The totality of changes resulting from the digital transformation (Industry 4.0, agricultural intelligence, e-commerce, *open banking*, *gig economy*) has led to the concept of digital government (e-government; e-state). It assumes (Sledziewska and Wloch, 2020):

- E-government – offering public services digitally via the Internet, which reduces costs and increases efficiency. One of the solutions being used are chatbots;
- Open government – a range of programs that promote transparency, citizen engagement and the digital economy;
- Data-centric government – the government collects citizens’ data for strategic purposes. Using open data from the government allows the development of innovative business applications;
- Smart government – implies full integration of administration, departments and agencies in terms of data systems and management. Public services are tailored to the needs of citizens, based on the data collected about them. This facilitates the management of both internal (public order) and external (military) security. See Figure 3.7 for more details.

Nationally, it can be considered that Denmark has the best-developed e-government and e-public services, with 91% of citizens using the Internet to contact the government and other public administrations. The EU average is 57% and there is a noticeable upward trend from 2010 (40%).

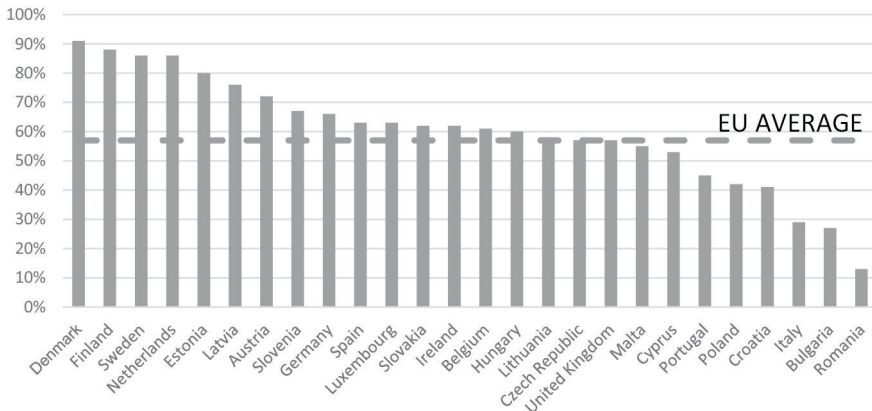


Figure 3.7 Share of people using the Internet to interact with public authorities.

Source: Eurostat (2023); Database: TIN00012.

3.7 Summary

The impact of digital transformation on traditional economic sectors is that emancipation of the digital economy is seen by society as a whole. While technological innovation, new scientific discoveries or the development of work on artificial intelligence are an area of interest for a handful, the dimensions of the digital economy discussed in this chapter affect everyone.

Agriculture, the most traditional sector of the economy, can dramatically increase productivity thanks to ICT technologies. Automation, autonomization and satellite-assisted precision agriculture are making it possible to reduce the number of workers needed while increasing yields, predicting natural disasters and raising farmers' incomes.

Industry 4.0 is a concept that involves the creation of smart factories, where machines communicate with one another and with workers. This reduces production losses, increases productivity and makes production with unprecedented flexibility possible.

E-commerce allows customers from all over the world to reach manufacturers without leaving home. They can compare prices, analyze other customers' opinions and personalize products. This, along with other digital services, creates a virtual marketplace for exchange that is disconnected from geographic location and based on cashless transactions.

Fintechs are a natural consequence of the technology industry's entry into finance. Small and flexible entities offer innovative and competitively priced services in payments, investments and currency trading (including cryptocurrencies). The coexistence of fintechs and traditional banks has created open banking, where information is exchanged between financial institutions through APIs.

The increasing digitization of all sectors of the economy, from agriculture to services, means that both the consumer and the worker must possess a certain array of digital skills. Without them, he or she is digitally excluded from society, unable to buy, unable to get information and even hampered in maintaining relationships with loved ones. A low level of digital skills makes it difficult to find one's place in a labor market that is further dynamizing and moving away from statism toward short-term contractual arrangements (gig economy). In addition, a lack of digital skills is holding back digital transformation.

The state must support the development of innovation understood as a developed digital economy, as this determines transparency and efficiency. Adequate education will raise the level of digital skills, so that the percentage of digitally excluded people decreases. Supported and competitive industry, trade and agriculture strengthen the economy through a positive trade balance resulting from product competitiveness. A modern financial system makes it easier to obtain financing for risky and innovative ideas. Such a booming economy requires a modern and flexible regulator and a digital state with online public services.

Note

1 Countries admitted to the European Union after 2004 are recognized as "New Union" countries.

4 The problem of measuring the development of the digital economy

4.1 Introduction

The concept of socio-economic development defines the totality of transformations that take place in a continuous or stepwise manner. Development is primarily qualitative in nature (Schumpeter, 1960). It is formed by changes in the structure, features or relations between features of an object. Often qualitative changes occur as a result of quantitative changes (Begg, Fisher and Dornbusch, 2007). Quantitative changes (economic growth) depend on the availability of natural, human, capital and technological resources (Samuelson and Nordhaus, 2012). These changes in turn cause changes in the economic sphere (production, consumption and employment) and in the political-legal, social and cultural system (Miszczuk, 2007).

To express the level of a given phenomenon, it is necessary to use a measure. It should meet the criteria of universality, measurability, interpretability and quality, and the primary data on which it is constructed should be characterized by relatively low costs of collection (Zelias, 2000). It is necessary to distinguish three exemplary ways in which variables affect the level of the studied phenomenon (Kompa, 2009):

- Stimulant – a higher value of the variable indicates a higher level of the phenomenon, so an increase in it causes development;
- Destimulant – a variable that has a negative effect on the phenomenon under study;
- Nominal variable – a variable that is neutral to the phenomenon under study.

Measuring the level of digital development of the economy and society is becoming increasingly important for determining development strategies. It is also important to regulate the direction and intensity of ICT use. This dictates the need for continuous improvement of the system, data collection methods and indicator analysis. It is crucial to adjust indicators so that they reflect the actual state of the digital development of all sectors of the economy and society. Developing a system of indicators helps properly assess the business climate, the quality of human capital and the degree of readiness for digital development. The next step in the development of indicators is to measure the effectiveness of ICT use in

production, management, education and social systems (Kuzvkova, Kuzovkov and Sharavova, 2019).

The purpose of this chapter is to review the methodological approaches used to quantitatively describe the digital economy followed by international organizations. This will allow us to understand the geographic variation in the performance of individual countries and identify the factors most relevant to its development. The digital economy, by its complexity described in Chapter 1, requires a holistic approach to measuring the pace of its development. The analysis of metrics to capture the stimulants of development as well as the effects of the degree of advancement of the digital economy is divided into four groups of measures for assessing the level of development: economic and social, technological, regulatory and administrative and human capital indicators, along with patent classification of the digital economy.

The chapter concludes with a review of methodological discussions on the possibility of using patent statistics in describing the digital economy. To this end, a search for works in the field of ICT dashboards was conducted, and modifications to better measure the digital economy were proposed.

4.2 Level of economic and social development

Socioeconomic development refers to the changes that society and the economy undergo. Development affects institutions that provide social services, the labor and housing markets, public safety and the general standard of living of a country's citizens (Strahl, 1998).

There are many approaches to measuring economic and social development in the literature. Often it comes down to the creation of synthetic measures, instead of selecting a group of indicators. Currently, the most common approach to comparing regions and economies in terms of the level of socioeconomic development is to use the GDP per capita. This indicator is fraught with a number of drawbacks, because it fails to indicate social stratification, inequality, infant mortality or illiteracy levels (Kompa, 2009). Hence, GDP per capita should be treated as a measure of economic growth, as it only plays the role of a quantifier.

Socioeconomic development should be analyzed taking into account all factors describing the spheres of human activity and life (Berbeka, 2006):

- Economic factors – changes in the level of economic development, the organization of the economy, government policies, the labor market and the degree of globalization;
- Social factors – interpersonal relationships, lifestyles, values and social norms;
- Demographic factors – structure, number and natural increase of population, population density and migration;
- Natural factors – geographical location, climatic conditions and environmental quality.

Adequate distribution of wealth is essential for proper development. Excessive concentration of wealth among a small group of people causes social inequality to

widen. Since the end of World War II, the incomes of the richest 10% of people have grown the fastest, while those of the middle class have grown the slowest. This phenomenon, criticized by most economists, examines the inequality between the 10% richest people and 90% of the rest of the planet's population. Historically, excessive stratification has led to violent upheavals (the Bolshevik Revolution in Russia and the French Revolution), so it seems reasonable to level the disparity. The best stimulant for improving the livelihood of the less well-off and middle class is economic development. It shows better efficiency than redistributive state policies (Gwiazda, 2015).

Modern economists must therefore find the golden mean between preserving a well-functioning capitalist free market and taxing the richest and state redistribution. French economist Thomas Piketty proposes imposing a wealth tax on the rich instead of an income tax. Inheritance and gift taxes play a similar role, redistributing the wealth inherited in traditionally rich families (Piketty, 2014). Here, the role of the state is crucial, which should simultaneously support entrepreneurial and innovative individuals who generate economic development, without leaving out the less well-off individuals. At this point, unfortunately, no such redistributive system has been developed that would not discourage the more entrepreneurial and capable from investing and multiplying wealth (Gwiazda, 2015).

Currently tested different approaches to the issue of redistribution will allow in the future to assess the long-term benefits and losses of the American model (free market) and at least the Scandinavian model (with a high rate of redistribution). Analyzing the current state using the Gini coefficient (used to measure the inequality of the distribution of random variables) in Scandinavian countries, it is observed that the level of social stratification is much lower in the United States.

At this point it is worth mentioning the idea of sustainable development. In simple terms, it means economic development that combines the needs of present and future generations. It assumes conscious and thoughtful use of resources and protection of the environment within the framework of so-called "intergenerational environmental justice". It requires the integration of political, economic and social actions (Sztumski, 2006). This is an issue that is all the more important in light of the digital economy, as this one requires the exploitation of raw materials (rare earth metals for autonomous cars, machines and computers) and the consumption of electricity (powering smart cities, factories, the Internet of Things). With the dynamic process of computerization and digitization, combined with the growth of the global population, prudence and conscious action are needed to avoid a climate catastrophe. Its avoidance is the only chance for further economic development. Sustainable development promotes social and economic integration, as creating modern networks increases labor productivity and the quality of human capital. This impacts the increasing efficiency of transportation, data exchange, production and energy generation (Greta and Tomcza-Wozniak, 2018). The digital component provides an opportunity to raise productivity in a world of limited energy resources while forcing the creation of new solutions as available resources shrink.

The digital economy requires two elements to develop: traditional economy and digital innovations. They allow the creation of a highly skilled workforce, the

generation of new technical solutions and adoption of initially expensive technical solutions. Only a society and an economy that are innovative and have an adequate standard of living are capable of developing Industry 4.0 and carrying out the digitization of the economy. Too low a level of socioeconomic development prevents both the generation and use of the solutions that the digital economy brings (digital illiteracy and exclusion).

Nowadays, the most widely used indicator of social development is the Human Development Index (HDI). It allows to present social development from a global, national and regional perspective. It was created by Mahbub ul Haq and Amartya Sen in 1990 for the United Nations. The intention of the creators was the flexibility of the index, which allows for gradual modification as new economic requirements emerge. The HDI index is composed of three areas measuring health, education and standard of living from which an arithmetic average is calculated. Over time, the literacy index, among others, was abandoned as it was no longer useful. In developed countries, it mostly oscillated around 100%. The change from GDP to GNI as a measure of the component of the standard of living resulted, among other things, from the European Commission Report (the so-called Stiglitz Report). It cited the inadequacies of GDP as a measure, which omits subsistence household work (e.g., childcare, food production) and the shadow economy (which distorted the indicator significantly for developing countries, where it is highly developed) (see Table 4.1). In addition, GNI shows a country's economic strength, as it takes into account the income earned by the country's residents abroad. Stiglitz also advocated using the median instead of the average, but the UN rejected this idea. The median would show inequality in wealth between the rich and the poor (Antczak, 2012).

However, the HDI index has not been adopted uncritically by the scientific community. Some researchers accuse it of overgeneralizing and simplifying the representation of variables. There are also voices accusing it of missing dimensions such as political freedom, human rights, happiness of residents or sustainability (Klugman, Rodriguez and Choi, 2011).

The value of each category's subindex is calculated by relating the size of the variable to the minimum and maximum values for all countries analyzed. This determines the HDI index values in the range 0,1. A country with an index value

Table 4.1 Changes in the components of the HDI index

<i>Dimension</i>	<i>Before 2010</i>	<i>Since 2010</i>
Health	Average life expectancy at birth	Average life expectancy at birth
Education	Adult literacy rate	Expected years of education for children entering school
	Gross enrollment ratio	Average training time for people over 25
Standard of living	Gross Domestic Product per capita PPP (in USD)	Gross National Income per capita PPP (in USD)

Source: Antczak (2012).

of below 0.5 is referred to as underdeveloped. A moderately developed country reaches values between 0.501 and 0.8. Above the value of 0.801 are highly developed countries. Among the countries belonging to the European Union, all are classified as highly developed. Bulgaria has the lowest score in 2019, while Ireland has the highest. The world leader is Norway (0.957) (Conceicao, 2020).

For the purpose of comparing the innovativeness of European Union economies, Eurostat and the OECD have created the European Innovation Scoreboard (EIS), the Regional Innovation Scoreboard (RIS) and the Community Innovation Survey (CIS).

The CIS is a statistical survey program that collects data on industrial and service entities (those with more than nine employees) through national statistical offices and ministries. Data are collected based on the following (Włodarczyk, 2020):

- The number of innovations introduced in the last three years;
- Amounts of expenditures on research and development activities;
- The impact of innovation on corporate performance;
- Sources of information in terms of innovation;
- Objectives of innovation activities;
- Collaboration with other entities when conducting innovation activities;
- Methods to protect innovations from competition and diffusion of innovations;
- Obstacles encountered.

The collected data are used to create innovation rankings at the national (EIS) and regional (RIS) levels. They are expanded to include data from the European Patent Office and the Office for Harmonization in the Internal Market. The results of the rankings are used to design the European Union's economic and science and technology (S&T) policies. The EIS uses 31 factors which are divided into 4 groups (Hollanders, 2021a):

- Framework conditions:
 - o Human resources;
 - New doctoral graduates in science, technology, engineering and mathematics (STEM) per 1,000 population aged 25–34;
 - Population with higher education aged 25–34;
 - o Attractive research systems;
 - International scientific publications per million population;
 - Percentage of scientific publications from a country among the top 10% most cited papers in the world;
 - Percentage of foreign doctoral students;
 - o Digitization;
 - Broadband Internet access (above 100 Mbps) by companies;
 - Share of population with above-average digital skills.
- Investments:
 - o Finance and support;
 - Public sector spending on research and development (R&D) activities (as % of GDP);

- Venture capital fund spending (as % of GDP);
- Direct government funding and tax support for the R&D sector;
- o Company investments;
 - Business expenditures on R&D (as % of GDP);
 - Non-R&D innovation expenditures (as % of turnover);
 - Innovation spending per person employed;
- o Use of information technology;
 - Number of companies providing training to develop and improve their employees' ICT skills;
 - Share of ICT specialists in total workforce.
- Innovation activities:
 - o Innovators;
 - Number of SMEs with innovative products;
 - Number of SMEs with business process innovations;
 - o Links;
 - Innovative SMEs working with others;
 - Public-private co-publications per million inhabitants;
 - Mobility of human resources in science and technology;
 - o Intellectual assets;
 - Intellectual assets reported to the European Patent Office (per billion GDP PPP);
 - Trademark applications (per billion GDP PPP);
 - Project applications (per billion GDP PPP).
- Impact:
 - o Employment impact;
 - Employment in knowledge-intensive activities;
 - Employment in innovative enterprises;
 - o Impact on sales;
 - Exports of medium- and high-tech products;
 - Exports of knowledge-intensive services;
 - Share of sales of new and improved products;
 - o Environmental sustainability;
 - Resource productivity;
 - Air emissions of particulate matter (PM 2.5);
 - Development of environmentally related technologies.

On the basis of the results, countries are assigned to one of the following four groups:

- Innovation leaders – for countries above 125% of the EU average;
- Strong innovators – for countries above 100% of the EU average;
- Moderate innovators – for countries between 70 and 100% of the EU average;
- Modest innovators – for countries below 70% of the EU average.

This indicator is accused of, among other things (Roszko-Wójtowicz and Białek, 2017):

- Weak theoretical underpinnings due to the lack of explicit citation of methodologies based on specific innovation models;
- Overly statistical perception of innovation;
- Strong focus on high technology with omission of other R&D;
- High correlation of some indicators by which there is a risk of a narrow focus of the EIS, for example, only on R&D activities;
- Completeness and availability of data;
- Impaired identification of stimulants;
- Focusing on inputs for innovation activities while ignoring the relationship of inputs to outputs.

The aforementioned problems of the index lead to distorted results. Researchers' attempts to analyze innovation taking into account not only inputs but also effects changes the status of a country. Sweden, which was among the innovation leaders according to the EIS, dropped to 23rd place after taking into account the efficiency of the innovation system (out of 28 countries). In 2014, it invested 7.35 times more than Bulgaria in the form of innovation inputs. At the same time, it achieved effects only 2.77 times greater than Bulgaria. This shows how the efficiency of the activities carried out is important in measuring a country's level of development (Edguist et al., 2018).

The Global Innovation Index (GII) is an annual ranking of countries in terms of their ability to generate and succeed in the field of innovation. It was created by Professor Soumitra Dutta. It is published by Cornell University, INSEAD and the World Intellectual Property Organization (WIPO) (Matthews and Brueggemann, 2015). Other institutions also contributed to the creation, while data comes from various sources including the International Telecommunications Union, the World Bank and the World Economic Forum (Aubert, 2010).

The GII is commonly used by corporate and government officials to compare countries according to their level of innovation. It is calculated by averaging the scores of two indices (Dutta, Lanvin and Wunsch-Vincent, 2020):

- Innovation input subindex:
 - o Institutions – the political, regulatory and business environment;
 - o Human and research capital – development of education, higher education and the research and development sector;
 - o Infrastructure – ICT development, environmental sustainability;
 - o Market sophistication – investment, market size, competitiveness, trade and access to capital;
 - o Business sophistication – white-collar workers, innovation linkage, knowledge absorption;
- Innovation output subindex:
 - o Knowledge and performance – knowledge creation, impact and diffusion;
 - o Creative outcomes – intangibles, creative goods and services, online creativity.

The indicator has been criticized for giving too much weight to factors that are not integral to innovation. Like the EIS, the GII indicator, despite being based on

Table 4.2 Summary of indicators of the level of socioeconomic development

<i>Country</i>	<i>HDI (2019)</i>	<i>EIS (2021)</i>	<i>GII (2020)</i>
Austria	0.922	Strong innovators	50.13
Belgium	0.931	Leaders of innovation	49.13
Bulgaria	0.816	Modest innovators	39.98
Croatia	0.851	Modest innovators	37.27
Cyprus	0.887	Moderate innovators	45.67
Czech Republic	0.900	Moderate innovators	48.34
Denmark	0.940	Leaders of innovation	57.53
Estonia	0.892	Strong innovators	48.28
Finland	0.938	Leaders of innovation	57.02
France	0.901	Strong innovators	53.66
Germany	0.947	Strong innovators	56.55
Greece	0.888	Moderate innovators	36.79
Hungary	0.854	Modest innovators	41.53
Ireland	0.955	Strong innovators	53.05
Italy	0.892	Moderate innovators	45.74
Latvia	0.866	Modest innovators	41.11
Lithuania	0.882	Moderate innovators	39.18
Luxembourg	0.916	Strong innovators	50.84
Malta	0.895	Moderate innovators	46.39
Netherlands	0.944	Strong innovators	58.76
Poland	0.880	Modest innovators	39.95
Portugal	0.864	Moderate innovators	43.51
Romania	0.828	Modest innovators	35.95
Slovakia	0.869	Modest innovators	39.70
Slovenia	0.917	Moderate innovators	42.91
Spain	0.904	Moderate innovators	45.60
Sweden	0.945	Leaders of innovation	62.47
United Kingdom	0.931	Strong innovators	59.78

Source: Own compilation based on Conceicao (2020); Hollanders (2021b); Dutta, Lanvin and Wunsch-Vincent (2020).

as many as 79 variables, is focused on innovation inputs (see Table 4.2). It ignores the issue of effects and the relationship between inputs and outputs. The effectiveness of activities that stimulate innovation is equally important and their omission narrows the usefulness of the index itself (Edquist et al., 2018).

The HDI index fails to recognize the digital dimension of social life, while the EIS does not sufficiently keep up with the accelerating digital transformation. The EIS measures only a narrow slice of the digital economy, while diluting the impact of digitization on, for example, trade, the environment or investments by business entities. The situation is similar for the GII index, where the index covers digital transformation only in a narrow scope that disappears from innovation activities in general. In addition, the GII focuses on inputs without analyzing the effects of innovation activities.

4.3 Level of technological development

Wanting to define technological development, we face the problem of the lack of a homogeneous definition of the terms “technique”, “technology” and “technological progress”. The term “technique” comes from the Greek word “*techné*”, which means art, skill, a way of practically performing certain activities. In the economic sphere, technique means a set of material means used to produce goods and services. Technique is also considered a synonym for technical equipment. The term “technology” means the science of technology (from the Greek “*techné*” and “*logos*”). It refers to the method of preparing and conducting a production process using practical and theoretical knowledge (Knosala, Palka and Stecula, 2018).

According to Lowe (1995), technology is the systematized use of scientific rules and practical knowledge. According to this definition, technology consists of: scientific rules and laws, specialized knowledge and methods, specific applications, a set of specific products produced through specific equipment and experience.

Gomulka (1998) defines technique and technology using the approaches of W.W. Leontief (1947) and M. Morishima (1976). A production process is a combination of inputs and one or more final products, which are obtained through various production methods. These methods are referred to as production techniques, and the set of all techniques is a technology.

An important challenge addressed by researchers is to determine the relationship between scientific and technological achievements and structural changes in the economy (Schumpeter, 1934; Arrow, 1962; Nelson and Winter, 1982; Freeman, 1982; Grossman and Helpman, 1991; Romer, 1990; Griliches, 1990). What is important here is the relationship between available resources and R&D expenditures and increased competitiveness. Key to this are organizational and technological changes.

The implementation of new technological solutions requires an adequate commercialization system and high human capital (education, creativity and knowledge absorption), which promote the diffusion of innovations (Bell and Pavitt, 1993). Investment in education creates cumulative development. The accumulation of technical knowledge generates more and more of society’s know-how which leads to a technological learning effect. Thanks to this in the initial stages of development, countries absorb and imitate foreign technologies in order to start producing their own solutions with their technical knowledge.

To keep their economies competitive, countries need to develop innovation at all levels from the micro to the macro level, which will transform the structure of their exports toward high-tech goods.

Technological development is therefore a sequence of innovative changes in the method of producing goods and services (including virtual goods that are the main products of the digital economy), moving from less to more advanced technical solutions and changes in technical parameters (speed, accuracy, quality or durability) (Okoń-Horodyńska, 1999), which, together with the development of technological knowledge, remodel the structure of the economy and its exports.

The changes observed in highly developed countries since the 1990s were due to the technological development of the ICT sector. The processes of production, distribution and exchange were restructured and knowledge-intensive and techno-intensive products became the main goods (Powell and Snellman, 2014). A knowledge-based economy (GOW) model has emerged (Powell and Snellmann, 2004). In this model, growth depends on knowledge-intensive activity that generates scientific and technological progress. ICT, R&D activity and technology diffusion are important in it (Munro, 2000). The GOW model has evolved into a digital economy, and the transition away from information exchange only between people is considered a limiting moment. In the digital economy, there is greater integration and automation of data exchange between humans and machines and between machines (Golinski, 2018).

The right configuration of knowledge, experience, skills, institutional structures and the interconnectedness of actors creates technical change, technological accumulation and ultimately technical progress. This can affect the total factor productivity in the economy which translates into economic growth (Bell and Pavitt, 1993). Technical changes materialize in the technical armament of labor, which affects production possibilities. In order for them to take place, it is necessary to accumulate technical and technological knowledge in advance through the accumulation of skills and competencies of producing industrial knowledge and using them during subsequent scientific and research work (Wisła, 2014).

In terms of the digital economy, to measure the level of technological development, it is necessary to focus on selected technologies from the ICT sector and measure the rate at which their use is increasing, market adoption, the rate of change of investment in them and the level of readiness for digital revolution. To do this, an analysis of two international indicators can be used.

Established in the late 19th century, the International Telecommunication Union (ITU) has as its main goal the facilitation of international communications networks, allocates global radio bands and satellite orbits, develops technical standards for wireless communications and seeks to improve ICT access for communities around the world.

The ICT Development Index (IDI), developed by the ITU, has been published annually since 2009. The score consists of 11 indicators and is used to measure, monitor and compare the development of information and communication technologies between countries over time. The index makes it possible to analyze the differences in the level of ICT development between developed and developing countries and determine the development potential of these technologies in the countries under study. The key premise is to recognize ICT development as a catalyst for economic development and enhancing the quality of social capital (development of skills and digital capabilities) (ITU, 2021).

Thus, the index allows to observe the development of ICT and the information society. This development can be divided into three stages. The first is the readiness of the economy, manifested in an adequate level of network infrastructure

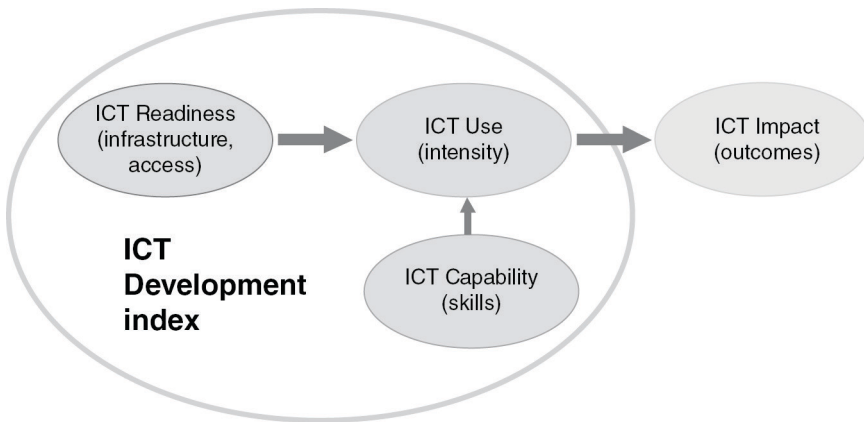


Figure 4.1 Three stages of evolution toward an information society.

Source: ITU (2021); www.itu.int/en/ITU-D/Statistics/Pages/IDI/default.aspx.

and access to ICT (ICT readiness). The second stage is the increasing use of ICT by people (ICT intensity). The third stage is the achievement of a more efficient and effective economy through the use of digital technologies (ICT impact) (ITU, 2017).

These are the three categories (Figure 4.1) under study:

- Access:
 - o Number of landline subscriptions per 100 residents;
 - o Number of cell phone subscriptions per 100 residents;
 - o Internet speed per user;
 - o Percentage of households with a computer;
 - o Percentage of households with Internet access.
- Usage:
 - o Percentage of individuals using the Internet;
 - o Number of fixed Internet subscriptions per 100 residents;
 - o Number of mobile broadband subscriptions per 100 residents.
- Skills:
 - o Average number of years of study;
 - o Number of people with secondary education;
 - o Number of people with higher education.

The World Economic Forum's Network Readiness Index (NRI) reveals technological readiness, measures countries' propensity to take advantage of opportunities from the ICT sector, and is one of the most authoritative and comprehensive methods for assessing the impact of ICT on nations' competitiveness and prosperity (World Economic Forum, 2015).

The NRI was first published in 2002 to comprehensively assess the multifaceted impact of digital and communications technologies on society and economic development. Until 2016, it was part of the Global Information Technology Report (GITR) published by the World Economic Forum (WEF), Cornell University and INSEAD. In 2019, for reasons of reorganization, the WEF outsourced the preparation of the index to the original creators of the index (Soumitra Dutta & Bruno Lanvin). NRI currently consists of four pillars (Dutta and Lanvin, 2020):

- Technology:
 - Access – Internet access, cell phone prices and subscriptions, 4G coverage, average Internet speed, Internet access in schools;
 - Content – the number of entries on Wikipedia, GitHub, the number of registered web domains and mobile applications created;
 - Future technologies – adoption of and investment in emerging technologies, number of ICT patents, software spending, number of industrial robots.
- People:
 - Units – number of Internet users, number of active mobile Internet subscriptions, adult illiteracy, digital literacy rate, people with higher education and social media use;
 - Enterprises – companies with their own website, number of ICT specialists, R&D spending in companies;
 - Government sector – digital government services, number of open access publications, R&D spending.
- Management:
 - Trust – secured servers, cyber security, online access to financial accounts, online shopping;
 - Regulation – privacy protection, legal framework for ICT development, quality of regulation;
 - Inclusion – availability of local online content, difference in percentage of women and men using the Internet, use of digital payments in rural regions.
- Impact:
 - Economy – developed medium and high-tech sector, high-tech sector exports, number of patents filed, worker productivity
 - Quality of life – life satisfaction, income inequality, social freedom, life expectancy;
 - Sustainability – quality of education, gender equality, cheap and clean energy, quality of health and well-being, modern and sustainable urban development.

These are summarized in Table 4.3.

IDI-based analysis of technological development identifies Denmark (8.71), the United Kingdom (8.65), the Netherlands (8.49), Luxembourg (8.47) and Sweden (8.41) as leaders. NRI, on the other hand, marks Sweden (82.75), Denmark (8.19), the Netherlands (81.37), Finland (80.16) and Germany (77.48) as leaders. Despite the slight differences, there is an apparent similarity between countries' rankings in both indexes. The NRI is used to create national digitization strategies. The leading

Table 4.3 Summary of indicators of the level of technological development

<i>Country</i>	<i>ICT development index (2017)</i>	<i>Network readiness index (2020)</i>
Austria	8.02	72.92
Belgium	7.81	70.67
Bulgaria	6.86	55.03
Croatia	7.24	55.94
Cyprus	7.77	60.67
Czech Republic	7.16	66.33
Denmark	8.71	82.19
Estonia	8.14	70.32
Finland	7.88	80.16
France	8.24	73.18
Germany	8.39	77.48
Greece	7.23	55.20
Hungary	6.93	60.05
Ireland	8.02	72.13
Italy	7.04	63.39
Latvia	7.26	60.47
Lithuania	7.19	64.70
Luxembourg	8.47	75.27
Malta	7.86	66.73
Netherlands	8.49	81.37
Poland	6.89	61.80
Portugal	7.13	64.40
Romania	6.48	54.16
Slovakia	7.06	60.78
Slovenia	7.38	66.58
Spain	7.79	67.31
Sweden	8.41	82.75
United Kingdom	8.65	76.27

Source: Own study based on ITU (2017); Dutta and Lanvin (2020).

countries in the IDI and NRI are economies with a strong focus on sustainability and social satisfaction (Scandinavia), an open and modern regulatory and educational approach (the United Kingdom) and heavy investment in digital infrastructure (Germany, Scandinavia).

4.4 Level of regulatory and administrative development

The dynamic development of technologies in the ICT sector and the digitization of economic life naturally create the need to regulate socioeconomic issues and redefine approaches to administration in the age of the digital economy. In the era of digitization, there is a discussion on intellectual property rights. Parties want to provide incentives for the development of creativity (through gratifications derived from authorship) while wanting to maintain easy access to science, culture and education (Wachter, 2014).

Antitrust law has a difficult task with the designation of relevant markets with regard to companies operating online. At the same time, the fight against monopolization (mainly from US giants like Alphabet, Apple, Microsoft and Amazon) is becoming an increasingly important topic in European regulatory policy. Through scalability and cross-border, US companies can dominate the European market by preventing the formation of local strong players in the digital sector. This is because potential competitors are quickly taken over by foreign capital. A separate challenge is brought by cloud storage. Within this, the discussion is on the topics of privacy, content sharing and copyright management. This is because the cloud is often treated as a place to distribute content without the author's permission (Szpringer, 2016).

A completely different aspect is the issue of digitization of public administration (e-government). E-government refers to the use of information and communication technologies in public administration to improve the quality of the services provided, strengthen citizen involvement in society and support government policies. Building e-government requires a major overhaul of existing structures, investment and information campaigns to make the public sector transparent and citizen-friendly. Efficient public administration that is closer to residents supports the country's competitiveness in the global market (Fleszer, 2014).

There was a definite acceleration in the digitization of public administration at the time of the SARS-CoV-2 (COVID-19) pandemic and lockdowns. E-government allowed access to government offices and doctors even during quarantine. This only confirmed the benefits of digitization of public administration such as (Brodniki, Kubiszewska and Tymoszek, 2012):

- Reducing service delivery time;
- Reducing the congestion of facilities, reducing the necessary area of offices and the service needed;
- Reducing the number of complaints and grievances by fully automating form filling;
- Increasing the rate of collection of public receivables through fully cashless cash circulation;
- Creating new services through integration of different levels of government and better availability of data and statistics.

Covered by digitization are services such as making a doctor's appointment, filing tax returns and paying dues, enrolling in college, accessing public library resources, obtaining a building permit, making out documents or changing registration details of registration. The goal is to enable citizens to handle all matters without leaving home. In addition, digitization makes it possible to systematize the work of offices and store information (Baron-Wiaterek and Grzanka, 2011).

To measure the digital economy and the challenges it faces in this way, indicators including e-government, online services and barriers to digital commerce should be analyzed.

Every two years, the UN Division of Public Administration and Development Management of the Department of Economic and Social Affairs (DPARM UN-DESA) conducts a survey on e-government. It compares 193 countries on the basis of surveys that quantitatively measure three indicators (United Nations, 2016):

- Online Service Index (OSI) – it measures the government’s presence on the Internet in terms of providing services there;
- Telecommunication Infrastructure Index (TII) – measures the level of development of a country’s telecommunications infrastructure;
- Human Capital Index (HCI) – this measures the level of human capital development (discussed in detail in Section 4.5).

e-Government development index (EDGI) allows comparative analysis of countries’ ability to transform digital government using ICT to provide online services to citizens and creates a benchmarking tool for the sophistication of e-government service implementation in the countries studied (Golinski, 2015). The indicator has received criticism for failing to measure the level of digital inclusion (LSE, 2019).

The OECD, a grouping of 37 highly developed countries, sought an indicator, to identify, catalog and quantify regulatory barriers affecting trade in digital services. The goal was to better align policies that support digital trade markets and competitiveness. The result was the OECD Digital Trade Restriction Index (DTRI), which identifies factors affecting 22 service sectors (including computer, audiovisual, financial and telecommunications). The index itself is based on data from five areas (Ferencz, 2019):

- Infrastructure and connectivity – seamless communication, limitations on offering communication services, network access, interconnection capabilities of operators, cross-border data flows;
- Electronic transactions – discriminatory conditions for issuing e-commerce licenses, registration of nonresident companies, measures that impede the use of electronic authentication;
- Payment systems – accessibility to specific payment methods, assessment of security standards, limitations associated with online banking;
- Intellectual property rights – copyright and trademark restrictions, enforcement mechanisms for copyright infringement;
- Other barriers affecting trade in digital services – restrictions on downloading and streaming, restrictions on online advertising, lack of effective redressal mechanisms against anticompetitive practices.

DTRI shows that in the European arena, Germany and France are the most regulated countries. These countries have more restrictive digital trade policies than most developed countries. In the third place is Romania. At the other extreme, among the countries with high digital openness are: Malta, the Netherlands, Latvia,

Table 4.4 Summary of regulatory and administrative development level indicators

<i>Country</i>	<i>E-Government Development Index (2020) (the more the better)</i>	<i>Digital Trade Restrictiveness Index (2018) (the less the better)</i>
Austria	0.8914	0.19
Belgium	0.8047	0.22
Bulgaria	0.7980	0.20
Croatia	0.7745	0.19
Cyprus	0.8731	0.18
Czech Republic	0.8135	0.18
Denmark	0.9758	0.22
Estonia	0.9473	0.18
Finland	0.9452	0.22
France	0.8718	0.36
Germany	0.8524	0.33
Greece	0.8021	0.24
Hungary	0.7745	0.23
Ireland	0.8433	0.13
Italy	0.8231	0.24
Latvia	0.7798	0.17
Lithuania	0.8665	0.21
Luxembourg	0.8272	0.17
Malta	0.8547	0.16
Netherlands	0.9228	0.17
Poland	0.8531	0.22
Portugal	0.8255	0.19
Romania	0.7605	0.27
Slovakia	0.7817	0.23
Slovenia	0.8546	0.18
Spain	0.8801	0.26
Sweden	0.9365	0.20
United Kingdom	0.9358	0.19

Source: Own compilation based on United Nations (2020); ECIPE (2018).

Luxembourg and Estonia. Thus, the most digitally open are small economies with relatively large service sectors (see Table 4.4).

Like indexes that measure the level of technological development, the EGDI and DTRI use variables to effectively measure the level of development of the digital economy. However, the EGDI relies directly on other indexes as subindices, while the DTRI uses data that were not available as a raw set. These reasons led to the methodology of these indexes not being used explicitly.

4.5 The level of development of social and human capital

In opposition to physical capital, the terms social capital and human capital emerged in the second half of the 20th century. The latter is more often used in

macroeconomic modeling. The term has been used since the 1960s and 1970s, thanks to the work of T. Schulz, G. Becker and J. Mincer, among others, who made it possible to study intangible elements of the economy such as the capabilities, knowledge or acquired skills of employees. Nowadays, human capital is defined as the value of human skills. These are all the qualities that affect the productivity of an individual (knowledge, education, intelligence, talents), which have a direct impact on productivity and labor outcomes (Kotarski, 2013).

Especially with the rise of the digital economy and new technologies, an educated workforce able to change frequently gives potentially greater competitive advantages. Better-trained employees with higher skills work better, making the economy grow faster. Thus, high levels of human capital translate into faster economic development (Heckman, 2001). Developing digital skills in the majority of the population makes it easier to find a job and reduces discrimination against those who are not digitally literate (digital exclusion).

Human capital is therefore an endogenous source of capital and wealth accumulation. It is another capital (labor) besides land, fixed assets and materials (Domanski, 1993; Stankiewicz, 1987; Miś, 2007). According to Nicholson (1891), it is capital embodied in people as opposed to land, buildings, machinery and other physical assets. Nicholson points out that the very concept of human capital also aroused the interest of researchers in the 18th and 19th centuries who took it into account when estimating the wealth of nations. In turn, A. Smith (1954) emphasized the necessity of spending on educating people, since the return on this investment is higher wages and better use of natural goods by him. In Mincer's (1958), human capital is the sum of knowledge acquired at school and experience gained on the job. He understood raising the level of human capital as a process of social learning that yields higher wages for labor.

Mincer (1958) focused on the income distribution of the population in his model examining human capital. He assumed, among other things, the possession of similar abilities, professional opportunities, no further training after graduation, or no global changes in an individual's labor productivity. From Mincer's model came the conclusion that an individual's earnings will be higher the higher their level of education (understood as the number of years of education). At the same time, as an individual grows older, the growth of earnings is impeded by the decreasing attractiveness of the employee in the eyes of the employer. The model does not take into account other determinants of wages or the worker's further education while working.

G.S. Becker (1962), in his model examining human capital, focused on ways to invest in it through on-the-job training and self-improvement through experience. He assumed perfect competition and an enterprise in equilibrium maximizing profit. In his research, Becker also searched for factors affecting investment in human capital. He pointed to the following as positively influencing human capital, among others:

- Higher life expectancy, higher return on investment in younger people;
- Greater return on self-investment for men than for women;

- Less investment in the skills of temporary migrants and commuters through less attachment to the workplace;
- A larger market giving greater investment in human capital and offering higher wages;
- A high rate of technical development that promotes investment in human capital by forcing the acquisition of new skills;
- Higher risk propensity of those more willing to invest in their skills.

The Ben-Porath (1967) model involves the use of human capital theory to analyze subjects' decisions. It also translates to issues of education, health, career choice and migration. Among the model's assumptions are a finite resource of time for work and further education, the possibility of unlimited borrowing at a fixed interest rate and a limited time horizon for an individual's planning. The model indicates that schooling is not the only method of investment in human capital. It is supplemented by work experience and on-the-job training. In countries with high enrollment rates, higher investment in human capital during earnings is norm.

In the literature, researchers typically use one of the following three methods to measure human capital (Le, Gibbon and Oxley, 2003):

- A method based on the educational level of human resources – the literacy rate or gross enrollment rate (the quotient of the number of students and the number of people in that age bracket), among others, is used. The enrollment rate is criticized, however, by the fact that students affect the production process only in later periods and is susceptible to significant demographic changes;
- Cost method (retrospective) – the total investment in human capital and the opportunity costs associated with it are taken into account. There is the problem of appropriate cost classification: discussion of expenses should be included in these costs;
- The income (prospective) method takes into account the distribution of wages based on gender, age, education, time worked, occupational group or economic sector. These methods are quite common by their simplicity, but an obstacle is often the lack of available statistical data in specific cross sections.

The aforementioned methods often do not take into account the quality of human capital and do not allow for the creation of international comparative analyses. For this reason, the study of the impact of human capital on economic growth uses simple indicators like (Roszkowska, 2013):

- Number of employees in R&D;
- Number of academic staff;
- Number of infant deaths per 1,000 live births;
- Total investment in education
- Percentage of population aged 25–64 with secondary and higher education;
- Enrollment rates at different levels of education;
- Life expectancy at birth;

- Relationship of years of education at each level to the basic;
- Relationships of average wages according to the level of education.

A concept more commonly used by sociologists is social capital. It is a relatively new concept, which became widespread thanks to the work of J. Coleman and R. Putnam in the 1980s. In its original sense, it is the characteristics of social organizations (individuals, households or entire communities) that through mutual relations, cooperation and trust can achieve more benefits. Social capital is an essential element of the emergence of civil society. Individuals wishing to achieve their goals cooperate, creating value (social networks). Informal ethical norms and values create a field for trust and this is “like a grease for increasing the efficiency of the functioning of any group and institution”. The main benefits of high social capital for the economic sphere are reduced transaction costs (related to contracting or litigation), the grassroots creation of large enterprises and more charitable organizations (Fukuyama, 1997).

Measuring social capital, like digital economies, poses problems through the multiplicity of definitions and the complexity of the issue. In this case, the researcher faces the difficulty of measuring phenomena such as trust or truthfulness. Issues of social engagement (participation in elections, volunteer membership, newspaper readership) are more commonly used these days. For its research, the World Bank uses trust in government institutions and strangers, social communication (conflicts and their resolution) and group activities, among others (Sierocinska, 2011).

The DESI monitors the dynamics of Europe’s digital transformation and tracks the progress of EU countries in their digital competitiveness. Conducted annually, the survey shows progress in digital connectivity, digital skills, online activity and digital public services. In this way, it is possible to assess the state of digitization of the member states and identify areas requiring additional action and investment (European Commission, 2020). The DESI is calculated based on indicators divided into five categories (Foley et al., 2021):

- Connectivity – access to fixed and mobile broadband, 4G network coverage of the country, readiness for 5G network, broadband prices, availability of ultrafast Internet (>100 Mbps);
- Human Capital – number of ICT professionals (and percentage of women in the industry), number of ICT graduates, number of people with basic and above-average digital skills, number of people with basic programming skills;
- Internet Usage – the number of people who have never used the Internet and regular users, use of music, movies, games, VOD (Video-On-Demand), social media, online banking, online shopping, video calling;
- Integration of Digital Technologies – number of SMEs selling online, international online sales, use of cloud computing, Big Data and social media, dissemination of electronic information;
- Digital Public Services – e-government users, electronic forms, digital services for businesses.

Initially, the normalized variables gained weights that changed their impact on the final index value. Connectivity was responsible for 25% of the index, Human Capital 25%, Internet Usage 15%, Digital Technology Integration 20% and Digital Public Services 15% (DESI, 2018). The methodology was modified in 2021, when the *Internet Usage* category was dropped. The current methodology assigns each of the four categories an equal weight of 25% (DESI, 2021). The change ignores public acceptance of the products of the digital economy, which can be equated with trust in new technologies.

It is worth considering whether unifying the weights was the right thing to do. Look at the performance of three countries – Denmark (the leader), Germany (the EU’s largest economy) and Poland (representative of the countries joined after 2004) – in five scenarios (DESI composite index):

- Overall: In the 2021 DESI index, Denmark was ranked No. 1, Germany No. 12 and Poland No. 24. Both Denmark and Germany performed above the EU average;
- Human Capital: Denmark is ranked 5th, Germany 16th and Poland 24th. Only Denmark is above average;
- Connectivity: Denmark is ranked No. 1, Germany No. 6 and Poland No. 20, with Denmark and Germany above the average;
- Digital Public Services – Denmark is ranked No. 1, Germany No. 19 and Poland No. 24. Only Denmark is above average;
- Digital Technology Integration – Denmark is ranked 5th, Germany 16th and Poland 22nd. Only Denmark is above the average.

In all variants, Poland ranks in distant positions (22–24) coinciding with the DESI ranking. In the category analysis, the leader of the overall DESI ranking (Denmark) in two out of four scenarios reaches as high as the fifth place. The most interesting differences are in the case of Germany – which in three of the four scenarios achieves similar positions to the overall ranking (16–19). The exception is *Communications*, in which they achieve sixth position. This is important because the *Connectivity* category brings together variables describing the development of the digital economy infrastructure necessary for its growth. *Connectivity*, therefore, shows the potential for development, so together with *Human Capital* they play the greatest role with stimulating further development of the digital economy. The weight of these two categories should therefore be summed up clearly higher than the regulatory aspect (*Digital Public Services*).

The economic aspect represented by Digital Technology Integration should also be expanded. Relevant and missing variables include ICT sector R&D expenditures as a % of total expenditures, ICT employment as a % of employment, ICT sector gross value added, ICT share of GDP, among others. Such an expanded category would more fully reflect the dynamics of the digital transformation of the economy.

After such a redesign, the proposed category weights would look as follows:

- Connectivity (technological aspect) – 30%;
- Human Capital (social aspect) – 30%;
- Integration of Digital Technologies (economic aspect) – 30%;
- Digital Public Services (regulatory aspect) – 10%.

The Human Capital Index (HCI) is implemented by the World Bank and measures the level of human capital that a child born today can expect to have by his or her 18th birthday. The HCI takes into account the risk of poor health and poor education, which reduce the economic and occupational potential of citizens. This allows an estimate that will show the expected productivity of a child as a future worker. Human capital values do not always go hand in hand with economic development, which is why some countries that are moderately developed in economic terms (GDP per capita) in terms of human capital are among the leaders. The index

Table 4.5 Summary of indicators of the level of development of human and social capital

<i>Country</i>	<i>DESI (2020) Ranking position</i>	<i>HCI (2020) Ranking position</i>
Austria	13	26
Belgium	9	19
Bulgaria	28	60
Croatia	20	31
Cyprus	24	21
Czech Republic	17	24
Denmark	3	22
Estonia	7	12
Finland	1	6
France	15	18
Germany	12	25
Greece	27	37
Hungary	21	40
Ireland	6	9
Italy	25	30
Latvia	18	33
Lithuania	14	34
Luxembourg	10	39
Malta	5	32
Netherlands	4	10
Poland	23	23
Portugal	19	17
Romania	26	78
Slovakia	22	44
Slovenia	16	14
Spain	11	29
Sweden	2	8
United Kingdom	8	11

Source: European Commission (2020); World Bank (2020).

itself is based on five indicators comprising three categories (World Bank, 2021a) (see Table 4.5):

- Survival – participation of children who have survived more than five years;
- Education – quality of education, exam results, expected length of schooling;
- Health – adult survival, stunted growth in children.

The HCI index ignores the issue of digitization entirely. The DESI, on the contrary, has a wide range of variables describing the changes resulting from the digital transformation. The magnitudes of the weights and the absence of many of the variables mentioned earlier in the subsection indicate the weakness of the index relative to assessing the macroeconomic impact of digitization.

4.6 Patent classification of the digital economy

The scientific literature recognizes the need to measure the role, dynamics and pervasiveness of digital technologies that make up the digital economy (Jorgenson, 2001; Bloom, 2012). Adequately measuring the development of digital technologies makes it possible to monitor the evolution of technological progress and their impact on economic development. It is necessary to adequately define these digital technologies to create a basket of solutions, products and industries. The most appropriate method for this seems to be the use of patent statistics showing the number of patents filed, their structure and the dynamics of change. However, this approach raises the problem of adequately defining the digital technologies that constitute the digital economy. This is due to the emergence of new technologies, not all of which are relevant from the perspective of the digital economy, while others are losing relevance and some end up in the collection due to the generalization of patent classifications.

Initially, the OECD (2002) used a definition of ICT that it had developed, which overlapped when first published with the International Patent Classification (IPC) connecting table. Unfortunately, this patent classification, from the perspective of two decades, shows symptoms of being out of date. It lacks technologies that have bloomed over the years like the Internet of Things or blockchain. The OECD (2006; 2008) has updated the definition of the ICT sector and products in successive iterations of its studies, which has further created a gap between the definition side and the patent table. For this reason, there is apparent room to update the definition of the digital technologies that make up the digital economy as well as to create a corresponding patent table. It is necessary to carefully analyze the patent codes in the currently available table, eliminate obsolete codes (e.g., typewriters) and add new ones (e.g., quantum computers).

Similar attempts to update the patent taxonomy over the years have been comprehended in a number of works by ISI-OST-INPI (2005), Schmoch (OECD, 2008) and the Japanese Patent Office, among others. The OECD (2002) classification was created by Ulrich Smoch and is based on IPC codes associated with information and communication technologies. They appear in four categories:

- Telecommunications (wires, data transmissions);
- Consumer electronics (audio-visual technologies, televisions, amplifiers);
- Computers and office machines (typewriters, computers);
- Other ICT (fiber optics, measurement equipment, traffic control systems and educational devices).

This classification needs to be updated, as it includes technologies-obsolete typewriters, thermoelectric devices, postal sorting machines. In addition, patents for measuring devices need to be clarified, as not all technologies are directly related to ICT. In 2008 and 2013, Schmoch revised the classification (OECD, 2008), which resulted in a list of 35 technologies grouped into 6 technology fields:

- Electrical engineering:
 - o Electrical machinery, apparatus, energy;
 - o Audiovisual technology;
 - o Telecommunications;
 - o Digital communications;
 - o Basic communication processes;
 - o Computer technology;
 - o Computerized management methods;
 - o Semiconductors.
- Instruments:
 - o Optics;
 - o Measurement;
 - o Analysis of biological materials;
 - o Control;
 - o Medical technology.
- Chemistry:
 - o Highly purified organic chemistry;
 - o Biotechnology;
 - o Pharmaceuticals;
 - o Macromolecular chemistry, polymers;
 - o Food chemistry;
 - o Basic chemistry of materials;
 - o Materials, metallurgy;
 - o Surface technology, coating;
 - o Microstructure and nanotechnology;
 - o Chemical engineering;
 - o Environmental technology.
- Mechanical engineering:
 - o Service;
 - o Machine tools;
 - o Engines, pumps, turbines;
 - o Textile and paper machinery;
 - o Other special machines;

- o Thermal processes and apparatus;
- o Mechanical components;
- o Transportation.
- Other fields:
 - o Furniture, games;
 - o Other consumer goods;
 - o Civil engineering.

Lacking in this classification is a separate category for ICT technologies, but they are present in the first category of electrical engineering.

A follow-up to Schmoch's classification proposals is the taxonomy developed by ISI-OST-INPI (OECD, 2017). The study is the result of joint work by Fraunhofer Institute Systems and Innovation Research, the French Office of Science and Technology and the French Institute of Industrial Property. It identifies a total of six technology fields:

- Electrical engineering:
 - o Electrical machinery and apparatus, electric power;
 - o Audiovisual Technology;
 - o Telecommunications;
 - o Information technology;
 - o Semiconductors.
- Instruments:
 - o Optics;
 - o Analysis, measurement, control technology;
 - o Medical technology;
 - o Nuclear engineering.
- Chemistry, pharmaceuticals:
 - o Good organic chemistry;
 - o Macromolecular chemistry, polymers;
 - o Pharmaceuticals, cosmetics;
 - o Biotechnology;
 - o Agriculture, food chemistry;
 - o Chemical and fuel industry, basic materials chemistry;
 - o Surface technology, coating;
 - o Materials, metallurgy.
- Process engineering, special equipment:
 - o Chemical engineering;
 - o Materials processing, textiles, paper;
 - o Operation, printing;
 - o Agri-food processing, machinery and apparatus;
 - o Environmental technology.
- Mechanical engineering, machinery:
 - o Machine tools;
 - o Engines, pumps, turbines;

- o Thermal processes and apparatus;
- o Mechanical components;
- o Transportation;
- o Space technology, weapons.
- Consumption:
 - o Consumer goods and equipment;
 - o Civil engineering, construction, mining.

The classification of the technology field of electrical engineering shows a lower level of detail. Here are only five subcategories, while in Schmoch's classification there are eight of them. It can be assumed that the OECD classification is thus more accurate, but its current form owes much to the ISI-OST-INPI table.

The Japan Patent Office (JPO) specializes in evaluating ICT-related technologies, which is evident in its liaison tables. In its tables, it rejects some of the patent codes that fall under the ICT group in international definitions but, upon closer examination, refer to other technological fields. It also adds previously overlooked codes, such as advanced alarm systems and technologies that did not exist in 2002 when the OECD first created its definition (nanotechnology, quantum computers). The full JPO taxonomy is not public, but there are reports using it available on the Office's website.

The JPO listed a total of 12 categories for ICT:

- High-speed networks;
- Safety;
- Home electronics networks;
- High-speed data processing;
- Simulation;
- Storage of large data sets;
- Input-output;
- Cognition and understanding of meaning;
- Assessment of human interactions;
- Software;
- Devices;
- Others.

Takashi Inaba and Mariagrazia Squicciarini (OECD, 2017), guided by the principles of expert judgement, relevance of the technology and related products in question, comprehensiveness of the view of ICT and precision to needs, have proposed the most accurate patent taxonomy for the digital economy to date. It builds on both previous OECD and JPO studies by adding new technologies that have emerged in recent years and are gaining prominence. The table thus compiled lists 13 technology fields and 25 subcategories.

In it, ICT technologies are grouped according to the most important technological areas with their corresponding codes from the International Patent Classification (see Table 4.6).

Table 4.6 Patent classification of ICT technologies

<i>Technology area</i>	<i>Subarea</i>	<i>IPC</i>
1. High-speed network	Digital communication technique Exchange, selecting Others	H03K, H03L, H03M, H04B1/69-1/719, H04J, H04L (excluding H04L9, H04L12/14) *H04L9, *H04L12/14 H04M3-13,19,99, H04Q H04B1/00-1/68, H04B1/72-1/76, H04B3-17 (excluding H04B1/59, H04B5, H04B7), H04H *H04B1/59, *H04B5, *H04B7
2. Mobile communication		H04B7, H04W (excluding H04W4/24, H04W12) *H04W24, *H04W12
3. Security	Cyphering, authentication Electronic payment	G06F12/14, G06F21, G06K19, G09C, G11C8/20, H04K, H04L9, H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727, H04N7/167-7/171, H04W12 G06Q20, G07F7/08-12, G07G1/12-1/14, H04L12/14, *G06Q30/02
4. Sensor and device network	Sensor network Electronic tag Others	G08B1/08, G08B3/10, G08B5/22-38, G08B7/06, G08B13/18-13/196, G08B13/22-26, G08B25, G08B26, G08B27, G08C, G08G1/01-065 *G06F17/10, *H04W48/18 H04B1/59, H04B5 *G01S13/74-84, *G01V3, *G01V15 *H04W84/10
5. High-speed computing		G06F5, G06F7, G06F9, G06F11, G06F13, G06F15/00, G06F15/16-15/177, G06F15/18, G06F15/76-15/82
6. Large capacity and high speed storage		G06F3/06-3/08, G06F12 (exclude G06F12/14), G06K1-7, G06K13, G11B, G11C (excluding G11C8/20), H04N5/78-5/907 *G06F12/14, *G11C8/20
7. Large-capacity information analysis	Database Data analysis, simulation, management	G06F17/30, G06F17/40 G06F17/00, G06F17/10-17/18, G06F17/50, G06F19, G06Q10, G06Q30, G06Q40, G06Q90, G06Q99, G08G (exclude G08G1/01-065, G08G1/0962-0969) *G08G1/01-065, *G08G1/0962-0969
8. Cognition and meaning understanding		G06F17/20-17/28, G06K9, G06T7, G10L13/027, G10L15, G10L17, G10L25/63.66 *G06F15/18

Table 4.6 (Continued)

<i>Technology area</i>	<i>Subarea</i>	<i>IPC</i>
9. Human interface		H04M1 (exclude H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727), G06F3/01-3/0489, G06F3/14-3/153, G06K13, G06K11, G06F11, G06G1/0962-0969, G09B5, G09B7, G09B9 *H04M1/66-665, *H04M1/667-675, *H04M1/68-70, *H04M1/727, *G06F17/50, *G06K9, *G06Q11, *G06T13, *G06T1/80
10. Imaging and sound technology	Imaging technique	H04N (excluding H04N5/78-5/907, H04N7/167-7/171), G06T1-9 (excluding G06T7), G06T11 (excluding G06T11/80), G06T13, G06T15, G06T17-19, *H04N5/78-5/907, *H04N7/167-7/171, *G06T7, *G06T11/80
	Sound technique	H04R, H04S, G10L (excluding G10L13/027), G10L15, G10L17, G10L25/63.66 *G10L13/027, *G10L15, *G10L17, *G10L25/63.66
11. Information communication device	Electronic circuit	H03B, H03C, H03D, H03F, H03G, H03H, H03J
	Cable and conductor	H01B11
	Semiconductor	H01L29-33, H01L21, 25, 27, 43-51
	Optic device	G02B6, G02F, H01S
12. Electronic measurement	Others	B81B7/02, B82Y10, H01P, H01Q
		G01S, G01V3, G01V8, G01V15
13. Others	Computer input-output	G06F3/00, G06F3/039, G06F3/12, G06F3/13, G06F3/18
	Other related technique	G06E, G06F1, G06F15/02, G06F15/08-15/14, G06G7, G06J, G06K7, G06N, H04M15, H04M17

Source: OECD (2017).

Missing but important technology fields are autonomous land vehicles (B60W), the Internet of Things (G16Y), industrial robots (B25J), 3D printing (B33Y) and drones – radio-controlled aerial vehicles (B64C 39/024).

4.7 Summary

The problem of measuring the digital economy manifests itself in identifying and giving appropriate weight to variables so that important factors are not overlooked. The digital economy goes beyond the field of technological development. On the basis of technical discoveries and concrete solutions (ICT), it has reorganized economic life. Economic and technological changes are forcing the creation of

new oversight mechanisms and regulations to protect businesses, workers and consumers from abuse, monopolization and competitive disruption. Thanks to the digital transformation, the state is beginning to provide public services in digital form (e-government), and this is forcing cyber security measures to protect personal and strategic data. Ultimately, the change in the functioning of society and the demand for digital skills at an ever higher level is creating an information society. This means that any discussion of comprehensively measuring the development and impact of the digital economy requires economic, technological, regulatory and social analysis.

In economic terms, traditional macroeconomic measures like GDP per capita PPP or GNI per capita PPP should be used to measure the development of the digital economy. The high affluence of society allows for greater emphasis on high-tech and innovative sectors. These measures should be expanded to include measures of the level of education, a high level of which is necessary to generate innovation. Hence the large role of measures like the length of the educational process, the number of scientific publications and the number of specialists in creative and knowledge-intensive industries. The economic perspective should additionally include variables measuring the degree of development of technical and scientific infrastructure such as access to broadband Internet, R&D expenditures and the number of patent applications

In terms of technology, ICT adoption, use of the Internet by citizens and businesses, development of e-commerce and cyber security are important. So it is important to measure investment in specific technologies, the number of mobile Internet subscribers and fixed line, the popularity of social media and the quality of education.

In administrative-regulatory terms, developed digital public services, technical infrastructure and the level of human capital are important. Measuring the quantity and quality of e-government services along with the development of Internet access (mobile and fixed) allows us to capture the development of the digital economy through the digitization of the contact of individuals and businesses with the state. The regulatory perspective can be measured through the amount of ease of communication and offering communication services, access to electronic transactions and secure payment systems, restrictions on e-commerce and protection of intellectual property.

In terms of human and social capital, it is important to measure digital skills and the building of the information society through variables such as access to the Internet, possession of at least basic digital skills and use of ICT in daily personal and professional life that allow measuring the dynamics of the digital economy. This is because in a digital economy, a person or business entity lacking digital skills and Internet access becomes digitally excluded. A large group of the “excluded” means slower dynamics of digital transformation.

An extension of the traditional macroeconomic methods of measuring indices is to look from the perspective of intellectual property. Patent analysis allows for tracking innovation activity among private and public entities. The key in this case is the creation of an appropriate link table for technology fields strictly related to the digital economy. This method requires regular updates resulting from technological developments.

5 Explanatory characteristics of the digital economy of EU countries

5.1 Introduction

The purpose of this chapter is to select characteristics describing the dynamics of the development of the digital economy in the studied group of European countries. All variables are from the Eurostat database, and missing values for single years were filled in by the nearest neighbor method. Variables available for most countries of the European Union and Norway for the period 2012–2019 were divided into two groups – supply-side variables and demand-side variables. The supply side of digitization is understood as the creation of infrastructure, conducting research and developing new products, while the demand side is the social acceptance of new technologies and their use. The time frame of the study was set to 2012–2019 for two reasons. The first was the availability of data, and the second was that this is the longest possible period of stability without the structural bumps that have been observed since 2020.

The variables thus selected were used to create a taxonomic index of digital saturation – a tool used to verify hypotheses one (the digital divide of Europe), two (the complementarity of the digital economy and human capital) and four (the demand and supply side of the digital economy).

5.2 Selection of explanatory characteristics of the digital economy

On the basis of the factors discussed related to the development of the economy (in Chapter 1), the practical dimensions of its application (in Chapter 3) and the indices used to describe the digital economy and society (in Chapter 4), Chapter 5 selects variables that, in light of current research, can describe the dynamics of the development of the digital economy as accurately as possible. Macro variables published by Eurostat for EU countries, the United Kingdom and Norway were used (see Table 5.1).

The review revealed that the working list of potential variables describing the digital economy at the macro level contains only 17 items. Owing to the continuous evolution of the digital economy phenomenon and its relative newness, some variables have become available only recently, making it impossible to measure their long-term impact on the traditional economy. The use of Big Data, artificial

Table 5.1 Variables related to the digital economy available in the Eurostat database

<i>L.p.</i>	<i>Variable name</i>	<i>Available time range</i>	<i>Code in Eurostat</i>
1.	Share of ICT sector in GDP	2008–2019	TIN00074
2.	Spending by companies on R&D	2011–2020	ISOC_BDE15AR2
3.	Sales value e-commerce	2012–2021	ISOC_EC_ESELN2
4.	ICT imports	2012–2020	EXT_TEC05
5.	ICT exports	2012–2020	EXT_TEC05
6.	Share of companies using 3D printing	2018–2020	ISOC_EB_P3D
7.	Share of people using e-commerce	2008–2019	TIN00096
8.	Share of companies using Big Data	2020–2020	ISOC_EB_BD
9.	Share of companies using artificial intelligence	2021–2021	ISOC_EB_AI
10.	Share of enterprises with Internet access	2012–2019	ISOC_CI_IN_EN2
11.	Share of people with basic and secondary digital skills	2021	TEPSR_SP410
12.	Number of people working remotely as % of employees	2012–2020	LFSA_EHOMP
13.	Share of ICT specialists in total workforce	2010–2019	ISOC_BDE15AP
14.	Share of companies employing ICT specialists	2012–2020	ISOC_SKE_ITSPEN2
15.	Participation of Internet users in dealing with public authorities.	2010–2020	TIN00012
16.	Share of population using online banking	2012–2020	ISOC_BDE15CBC
17.	Share of companies reporting cyber security problems	2010–2019	ISOC_CISCE_IC

Source: Own compilation based on Eurostat.

intelligence and 3D printing in companies only appears in public statistics as of 2018. Only at the end of 2023, the incidentality of measuring and presenting quantitative data from these areas can be confirmed.

Among the other variables, data for 2021 is often missing, as well as for 2020, forcing the upper limit of the range to be set at 2019. The lower limit of the interval (2012) is also due to data availability. The selection of countries is also determined by the availability of data for certain variables and time series. As a result, it was necessary to eliminate Cyprus, Luxembourg, Ireland and Portugal from the study.

After the initial selection of macro variables relating to the digital economy, these variables were finally divided into two groups: supply and demand.

5.3 Group of supply-side variables

The first characteristic, considered valuable, is the *Share of ICT professionals in total employment*. This variable shows the total number of ICT professionals employed in the ICT sector in the observed units.¹

The ICT sector is defined as ICT production (electronic components, computers, communication devices, optical, magnetic) and ICT services (information sales,

Table 5.2 Share of ICT professionals in total employment in selected European countries in 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	2.66	2.73	2.63	2.6	2.65	2.69	2.85	2.96
Bulgaria	2.02	2.13	2.19	2.37	2.59	2.71	2.85	3.01
Czech Republic	2.79	2.76	2.81	2.84	2.96	3.07	3.13	3.25
Denmark	4.15	4.15	4.15	3.83	3.51	3.51	3.51	3.6
Germany	2.36	2.47	2.6	2.66	2.74	2.82	3.16	3.13
Estonia	3.41	3.48	3.58	3.6	3.69	4.09	4.3	4.75
Greece	1.37	1.23	1.48	1.44	1.42	1.44	1.46	1.54
Spain	2.21	2.19	2.21	2.21	2.345	2.48	2.48	2.48
France	2.91	2.84	2.99	2.96	2.97	3.07	3.07	3.1
Croatia	1.93	2.21	2.24	2.34	2.39	2.49	2.57	2.67
Italy	2.37	2.38	2.32	2.35	2.42	2.44	2.43	2.45
Latvia	2.47	2.62	3.03	3.28	3.59	3.84	4.15	4.13
Lithuania	1.98	2.07	2.22	2.36	2.46	2.57	2.64	2.79
Hungary	3.64	3.53	3.41	3.42	3.49	3.56	3.6	3.75
Malta	4.05	3.97	4.13	4.42	4.64	4.69	4.71	4.71
Netherlands	3.06	3.06	3.06	3.06	3.06	3.06	3.06	3.06
Austria	2.38	2.43	2.455	2.48	2.55	2.61	2.63	2.69
Poland	1.84	1.91	2	2.14	2.29	2.47	2.54	2.7
Romania	1.71	1.84	1.95	2.1	2.27	2.36	2.52	2.63
Slovenia	2.41	2.52	2.52	2.61	2.63	2.66	2.72	2.78
Slovakia	2.79	2.825	2.86	2.92	3.04	3.18	3.31	3.35
Finland	3.8	3.7	3.7	3.7	3.715	3.73	3.79	3.87
Sweden	-	-	4.49	-	-	-	4.8	4.93
Norway	2.9	2.9	2.95	3	2.96	3.03	3.08	3.19
United Kingdom	3.09	3.32	3.41	3.47	3.6	3.64	3.43	3.43

Source: Eurostat (n.d.); Database: TIN00085.

software, telecommunications services, consulting, data processing and analysis of data, hosting, web portals, computer hardware repair).

Table 5.2 presents the percentages of ICT professionals in the total workforce in the economies of the analyzed European countries in 2012–2019.

Share of ICT specialists in total workforce

In 2012, the leaders in the share of ICT professionals in total employment were Denmark, Malta, Finland, Hungary and Estonia. After seven years, in 2019, the top performers were: Estonia, Malta, Latvia, Finland and Hungary. The lowest ICT employment in 2012 was in: Greece, Romania, Poland, Croatia and Lithuania. In 2019, the lowest scores were in: Greece, Italy, Spain, Romania and Croatia

There is also a noticeable change in the spread of results. Year 2012 witnessed the worst: Greek score (1.37%) was separated from Denmark's (4.15%) by 2.78 percentage points. In 2019, the best score rose to 4.75% (Estonia), while the bottom score rose to 1.54% (Greece). In seven years, the spread in the employment

performance of ICT specialists increased to 3.21 percentage points. The average spread score for the surveyed countries increased from 2.68% (2012) to 3.17% (2019). Thus, one can see the relative stability of the variable, which admittedly records higher values during the period under review, but the gradation of countries does not change significantly.

In 2012, 11 countries (including 5 countries of the New Union: Malta, Hungary, Estonia, Czech Republic and Slovakia) scored above average. In 2019, the result above the average had 10 countries scored above the average, and the New Union already had 6 representatives (Estonia, Malta, Latvia, Hungary, Slovakia and Czech Republic). The trend of shifting the center of gravity from the south of Europe to the east is evident. Latvia had the strongest increase, from 2.47% to 4.13%, which promoted it to the third place among the countries surveyed. At the same time, Denmark (down 0.13 percentage points) was the only country to reduce the share of employed ICT professionals. These observations also point to the higher growth dynamics of the New Union countries.

In 2012–2019, the standard deviation of the *Share of ICT professionals in total employment* fell from 0.742 to 0.72, while the quarterly deviation of this variable fell from 0.453 to 0.388. At the same time, the coefficient of variation based on the standard deviation of this variable (the quotient of the standard deviation and the arithmetic mean) fell from 0.277 to 0.227. At the same time, the coefficient of variation based on the quarter deviation of the analyzed variable (the quotient of the quarter deviation and the median) fell from 0.177 to 0.126. The trend of increasing employment of digital specialists is evident as the performance of each country levels out.

Figure 5.1 shows the quintile groups of the share of ICT professionals in the overall employed population in 2012 and 2019. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied trait.



Figure 5.1 Share of ICT specialists in total workforce in 2012 and 2019.

Source: Own compilation based on Eurostat.

The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions are drawn from Figure 5.1:

- In the first quintile group in 2012. (taking values from 3.22 to 4.15) were: Denmark, Estonia, Hungary, Malta and Finland. In 2019, Estonia, Hungary, Malta, Finland and Latvia were in the first quintile group (taking values from 3.66 to 4.75);
- In the second quintile group in 2012 (values from 2.79 to 3.22) were the Czech Republic, France, the Netherlands, Slovakia, Norway and the United Kingdom. In 2019: Denmark, the Czech Republic, Slovakia, Norway and the United Kingdom were in the second quintile group (values from 3.18 to 3.66);
- In the third quintile group in 2012 (values from 2.42 to 2.79) were Belgium and Latvia. In 2019, France, the Netherlands and Germany were in the third quintile group (values from 3.02 to 3.18);
- In the fourth quintile group in 2012 (values from 2.0 to 2.42) were Bulgaria, Germany, Spain, Italy, Austria, Slovenia. In 2019, in the fourth quintile group (values from 2.68 to 3.02) were Belgium, Bulgaria, Austria, Slovenia, Lithuania and Poland;
- In the last quintile group in 2012 (values from 1.37 to 2.0) were Greece, Croatia, Lithuania, Poland and Romania. In 2019, Spain, Italy, Greece, Croatia and Romania were in the last quintile group (values from 1.54 to 2.68).

From an analysis of Figure 5.1, we can infer country shifts between quintile groups:

- Belgium dropped from group three to group four;
- Denmark dropped from group one to group two;
- France and the Netherlands dropped from group two to group three;
- Germany advanced from group four to group three;
- Lithuania and Poland advanced from the last group to the fourth;
- Spain and Italy dropped from the fourth to the last group;
- Latvia was promoted from group three to group one which makes this the largest shift between groups.

The second characteristic is the *ICT sector's share of value added in GDP (in factor costs)*. The ICT sector is defined in the same way as the *Share of ICT professionals in total employment*.

ICT sector value added in GDP

Table 5.3 presents the percentage share of the information and communications sector in the creation of gross value added for the entire economy in 2012–2019 for 25 European countries.

Table 5.3 shows that in 2012, the countries with the highest share of ICT in GDP were Malta, Sweden, Hungary, United Kingdom and the Netherlands. In 2019, they

Table 5.3 Share of ICT sector value added in GDP in selected European countries in 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	4.13	4.03	3.82	3.79	3.78	3.75	3.97	4.21
Bulgaria	4.53	4.69	4.88	5.02	5.36	5.72	6.07	6.62
Czech Republic	4.35	4.34	4.27	4.24	4.27	4.36	4.56	4.71
Denmark	4.62	4.62	4.62	4.59	4.56	4.56	4.56	4.46
Germany	4	4.08	4.17	4.23	4.13	4.18	4.39	4.37
Estonia	4.7	4.6	4.83	4.74	4.9	5.12	5.41	5.98
Greece	2.08	1.99	1.96	2.18	2.16	1.96	2.49	2.27
Spain	3.37	3.31	3.2	3.2	3.245	3.29	3.29	3.29
France	4.01	3.92	3.83	3.89	4	4.33	4.31	4.41
Croatia	3.85	4.05	4.02	4.14	4.16	4.31	4.38	4.48
Italy	3.47	3.24	3.21	3.22	3.27	3.33	3.29	3.35
Latvia	3.46	3.74	3.74	4.15	4.53	4.69	4.92	5.41
Lithuania	2.47	2.38	2.57	2.93	2.95	3.01	3.13	3.5
Hungary	5.69	5.78	5.58	5.71	5.62	5.96	5.95	6.13
Malta	8.44	6.55	6.9	6.86	6.61	8.19	7.72	7.66
Netherlands	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
Austria	3.15	3.23	3.3	3.37	3.46	3.49	3.58	3.66
Poland	3.14	3.03	3.07	3.14	3.21	3.33	3.59	3.62
Romania	3.19	3.14	3.31	3.36	3.56	3.53	3.74	3.74
Slovenia	3.55	3.56	3.59	3.6	3.59	3.67	3.59	3.72
Slovakia	4.7	4.44	4.18	4.35	4.01	4.3	4.13	4.31
Finland	3.62	4.32	4.43	4.54	4.98	5.42	4.85	4.91
Sweden	6.275	6.28	6.28	6.28	6.11	5.94	5.94	6.48
Norway	3.2	3.19	3.3	3.41	3.42	3.43	3.37	3.77
United Kingdom	5.525	5.67	5.67	5.81	5.87	5.97	6.15	6.15

Source: Eurostat (n.d.); Database: TIN00074.

were: Malta, Bulgaria, Sweden, the United Kingdom and Hungary. The lowest performers in 2012 were Greece, Lithuania, Poland, Austria and Romania. In 2019, they were: Greece, Spain, Italy, Lithuania and Poland. During the period under review, Malta maintained its leading position, which may indicate the stable and concentrated development of the country's technology sector. Changes in the composition of countries with the lowest share of ICT in GDP, including the emergence of Spain and Italy instead of Austria and Romania, may reflect differences in economic policies, ICT investment and the overall economic health of these countries during the period under review.

There is a noticeable change in the spread of results. In 2012, the worst score of 2.08% (Greece) and the best score of 8.44% (Malta) were separated by 6.38 percentage points. In 2019, the best score was again given to Malta (7.66%), and the weakest to Greece (2.27%). The difference fell to 5.39 percentage points. At the same time, the average score of the countries surveyed increased from 4.18% to 4.64% in 2019. The narrowing of the gap between the extremes, while the average

has increased, may be indicative of more effective policy and investment efforts in countries with lower ratios, contributing to the reduction of digital development disparities at the international level.

An overall increase in the share of the ICT sector's value-added in the GDP of European countries has been observed, with increasing convergence in the performance of individual countries. In 2012, 10 countries had an above-average score including 6 countries of the New Union (Malta, Hungary, Estonia, Slovakia, Bulgaria and Czech Republic). In 2019, the above-average result also had 10 countries of which 6 were representatives of the New Union (Malta, Bulgaria, Hungary, Estonia, Latvia and Czech Republic).

The biggest advances were in Latvia (up 0.56 percentage points), Bulgaria (0.46 percentage points) and Lithuania (0.42 percentage points). Declines in the index were recorded in 5 countries: Spain (-0.02 percentage points), Italy (-0.03 percentage points), Denmark (-0.03 percentage points), Slovakia (-0.08 percentage points) and Malta (-0.09 percentage points). The decline in the index in countries such as Spain, Italy, Denmark, Slovakia and Malta may suggest various scenarios, including the maturation of the ICT market, shifts in the economic structure or challenges in maintaining the growth rate of the ICT sector in the face of global competition. An interesting case is Malta, which, despite the decline, continues to hold the top position, which could mean that its ICT sector has reached saturation or is focusing on consolidating the positions it has gained.

Between 2012 and 2019, the standard deviation of the study variable fell from 1.323 to 1.27, while the quarterly deviation increased from 0.665 to 0.845. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.317 to 0.274. At the same time, the coefficient of variation based on the quarterly deviation (the quotient of the quarterly deviation and the median) increased from 0.166 to 0.192.

This means that from 2012 to 2019, the dispersion of *Value added in the ICT sector relative to value added in the national economy as a whole (in factor costs)* decreased. At the same time, the average variation of the variable around the median has increased, so the boundary values of the various quintile groups have become more stratified.

Figure 5.2 shows quintile groups of the share of ICT professionals in GDP in 2012 and 2019. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied trait. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions are drawn from Figure 5.2:

- In the first quintile group in 2012 (taking values of 4.74 to 8.44) were: Hungary, Malta, the Netherlands, Sweden and the United Kingdom. In 2019 in the first quintile group (values from 6.01 to 7.66) were: Hungary, Malta, Sweden, United Kingdom and Bulgaria;
- In the second quintile group in 2012 (values from 4.22 to 4.74) were: Bulgaria, Czech Republic, Denmark, Estonia and Slovakia. In 2019, in the second quintile

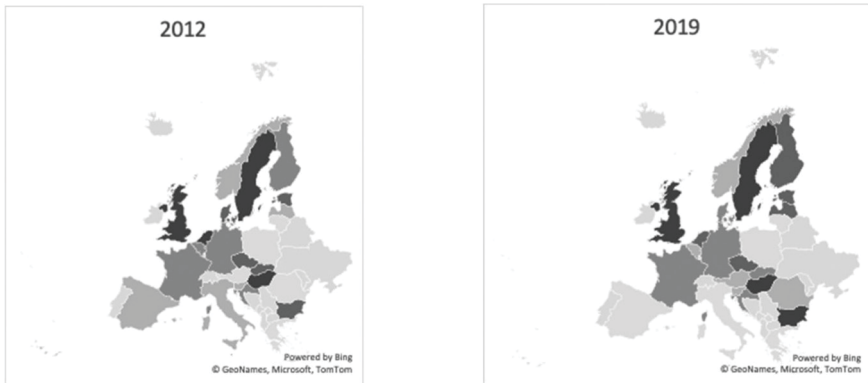


Figure 5.2 Share of the ICT sector's added value in GDP in selected European countries in 2012 and 2019 (in %).

Source: Own compilation based on Eurostat.

group (values from 4.57 to 6.01) were: the Netherlands, Czech Republic, Estonia, Finland and Latvia;

- In the third quintile group in 2012 (values from 3.59 to 4.22) were: Belgium, Germany, France, Croatia and Finland. In 2019, in the third quintile group (values from 4.27 to 4.57) were: Denmark, Slovakia, Germany, France and Croatia;
- In the fourth quintile group in 2012 (values of 3.2 from to 3.59) were: Spain, Italy, Latvia, Slovenia and Norway. In 2019, in the fourth quintile group (values of 3.65 to 4.27) were: Belgium, Slovenia, Norway, Austria and Romania;
- In the last quintile group in 2012 (values from 2.08 to 3.2) were: Greece, Lithuania, Austria, Poland and Romania. In 2019, in the last quintile group (values from 2.27 to 3.65) were: Spain, Italy, Greece, Lithuania and Poland.

From an analysis of Figure 5.2, we can infer country shifts between quintile groups:

- The Netherlands dropped from group one to group two;
- Denmark and Slovakia dropped from group two to group three;
- Belgium dropped from group three to group four;
- Spain and Italy dropped from the fourth to the last group;
- Bulgaria was promoted from group two to group one;
- Finland advanced from group three to group two;
- Austria and Romania advanced from the last group to the fourth;
- Latvia was promoted from group four to group two, the largest shift between the groups.

The third variable is the *Nominal value of ICT imports of European countries* in terms of millions of euros.² Only the value of imports related to the digital economy (information and communication) to all countries in the world was used. The selection of the information and communication sector is made on the basis of the NACE classification (French: *Nomenclature statistique des Activités économiques dans la Communauté Européenne*; statistical classification of economic activities in the European Union). Section J of this classification covers the production and dissemination of information and cultural goods, the transmission or dissemination of such goods, information technology service activities, data processing and other information service activities.

ICT Import

Table 5.4 shows the value of ICT imports in 2012–2019 for 25 European countries. Values are expressed in millions of euros and are adjusted for inflation.

In 2012, the largest ICT imports are from the United Kingdom, the Netherlands, Germany, France and Italy. In 2019, the highest values are in the United Kingdom, Germany, France, the Netherlands and Sweden. The lowest results in 2012 are in: Malta, Latvia, Lithuania, Estonia and Slovenia. In 2019, the lowest imports are in Malta, Estonia, Latvia, Croatia and Lithuania. The analysis of ICT imports shows stability among the major technology importers in Europe, with countries such as the United Kingdom, Germany, France and the Netherlands maintaining their leadership positions in both 2012 and 2019. Sweden's inclusion among the top five importers in 2019 may reflect its growing interest in ICT sector development and investment in new technologies. On the contrary, the consistently low ICT imports of countries such as Malta, Latvia, Lithuania, Estonia and, in 2019, Croatia, may reflect lower market demands or limitations in access to financial resources for greater investment in the technology sector. This diversification shows how countries' strategies for developing and implementing modern digital technologies differ.

The total value for the countries surveyed fell from €51.889.12 million to €45.313.84 million. Similarly, the average value of ICT imports fell from €2.075.56 million to €1.812.55 million. Malta (up 512.88%), Slovenia (up 80.62%), Latvia (up 56%), Austria (up 46.54%) and Germany (up 41.09%) showed the fastest growth. For 10 countries, inflation-adjusted imports were lower in 2019 than in 2012 (in Romania, Estonia, Spain, Italy, Poland, Croatia, the United Kingdom, the Netherlands, Norway and Greece). The largest declines were recorded in Greece (down 57.21%), Norway (down 41.42%), the Netherlands (down 39.84%) and the United Kingdom (down 37.57%)

The decline in the total value of ICT imports and the average value of imports in the countries studied may indicate a general change in the dynamics of the ICT market and communication technologies in Europe during the period under review. This could be due to factors such as market saturation, changes in purchasing preferences, increased domestic production or changes in global supply chains. The dynamic growth of imports in countries such as Malta, Slovenia, Latvia,

Table 5.4 The value of ICT sector imports in selected European countries in 2012–2019 (in EUR million)

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Belgium	1 313.02	1 500.29	1 614.33	1 975.69	2 077.37	2 215.98	1 740.90	1 527.60
Bulgaria	193.37	177.00	195.54	286.25	290.90	275.50	184.33	223.61
Czech Republic	414.35	365.77	322.82	387.67	387.34	382.91	373.07	415.88
Denmark	1 377.59	1 368.55	1 360.92	1 419.97	1 362.24	1 290.86	1 278.64	1 404.76
Germany	5 865.24	6 033.97	7 372.55	8 114.14	7 076.76	6 887.57	9 004.67	8 275.51
Estonia	169.63	150.04	130.83	173.36	171.45	165.01	160.16	157.12
Greece	730.16	435.27	427.21	374.54	636.90	436.04	369.99	312.46
Spain	1 972.64	1 563.43	1 713.26	2 161.37	2 126.34	1 880.42	1 983.53	1 785.30
France	5 525.73	4 894.20	6 714.26	7 843.66	8 541.19	7 969.24	7 026.19	6 166.73
Croatia	304.48	312.70	315.05	384.89	334.74	331.41	311.92	192.21
Italy	2 618.88	2 587.83	2 582.66	2 892.68	2 607.12	2 526.54	2 267.46	2 276.44
Latvia	117.76	115.48	131.58	130.51	139.82	142.80	167.49	183.71
Lithuania	148.08	135.26	132.15	134.92	146.06	158.70	173.62	194.48
Hungary	335.88	413.85	397.66	439.84	455.44	499.20	437.21	388.78
Malta	4.31	3.89	22.17	30.01	28.68	27.26	26.80	26.40
Netherlands	7 256.81	7 072.91	7 051.76	4 900.46	3 406.76	3 808.12	4 510.58	4 366.01
Austria	772.32	773.10	708.35	793.39	892.14	975.65	1 076.06	1 131.76
Poland	1 270.28	1 642.69	1 477.10	1 473.16	1 111.64	951.14	927.73	896.77
Romania	482.55	425.13	511.34	563.20	610.37	599.56	526.71	462.70
Slovenia	167.34	177.70	193.97	250.36	241.65	269.73	325.53	302.25
Slovakia	452.89	446.20	478.43	567.46	470.29	438.81	494.85	474.90
Finland	772.63	787.73	812.15	982.71	905.51	1 058.17	1 355.87	1 022.96
Sweden	2 709.79	2 610.49	2 885.76	2 848.61	4 163.30	3 401.33	3 403.69	3 001.87
Norway	1 514.82	1 485.12	1 457.42	1 428.85	1 344.12	1 205.60	1 039.15	887.39
United Kingdom	14 794.87	14 458.77	12 996.55	13 380.62	11 760.49	8 987.62	9 402.48	9 236.23

Source: Eurostat (n.d.); Database: EXT_TEC05.

Austria and Germany suggests an increase in ICT investment by these countries, which may indicate their strategic focus on digital development and innovation as key elements of economic growth. Declines in ICT import values, in countries such as Romania, Estonia, Spain, Italy, Poland, Croatia, the United Kingdom, the Netherlands, Norway and Greece, may reflect economic challenges, such as the financial crisis that occurred in the first half of the period under review, or strategic shifts toward self-sufficiency in ICT production. The largest declines in Greece, Norway, the Netherlands and the United Kingdom may also indicate particularly difficult economic conditions or political changes affecting technology imports.

Between 2012 and 2019, the standard deviation fell from 3288.69 to 2545.36, while the quarter deviation increased from 834.08 to 741.53. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 1.603 to 1.404. Over the same period, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) fell from 1.08 to 0.836.

This means that from 2012 to 2019, the dispersion *Nominal value of ICT imports of European countries* has declined and a progressive convergence of this variable is evident.

Figure 5.3 shows quintile groups of ICT import volumes in 2012 and 2019 in selected European countries. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions are drawn from Figure 5.3:

- In the first quintile group in 2012 (taking values from €2.64 billion to €14.79 billion) were: Germany, France, the Netherlands, Sweden and the United



Figure 5.3 ICT import value in 2012 and 2019.

Source: Own compilation based on Eurostat.

Kingdom. In 2019, the first quintile group (taking values from €2.42 billion to €9.24 billion) invariably: Germany, France, the Netherlands, Sweden and the United Kingdom;

- In the second quintile group in 2012 (values from €1.29 billion to €2.64 billion) were: Belgium, Denmark, Spain, Italy and Norway. In 2019, Belgium, Denmark, Spain, Italy and Austria were consistently in the second quintile group (values from €1.07 billion to €2.42 billion);
- In the third quintile group in 2012 (values from EUR 0.47 billion to EUR 1.29 billion) were: Greece, Austria, Poland, Romania and Finland. In 2019, in the third quintile group (values from EUR 0.44 billion to EUR 1.07 billion) were: Norway, Poland, Romania, Finland and Slovakia;
- In the fourth quintile group in 2012 (values from EUR 0.19 billion to EUR 0.47 billion) were: Bulgaria, Czech Republic Croatia, Hungary and Slovakia. In 2019, in the fourth quintile group (values from EUR 0.22 billion 0.44 to EUR 0.47 billion) were: Greece, Bulgaria, Czech Republic, Hungary and Slovenia;
- In the last quintile group in 2012 (values ranging from €4.31 million to €188.62 million) were: Estonia, Latvia, Lithuania, Malta and Slovenia. In 2019, in the last quintile group (values from EUR 26.4 million to EUR 217.79 million) were: Croatia, Estonia, Latvia, Lithuania and Malta.

From an analysis of Figure 5.3, we can infer country shifts between quintile groups:

- o Norway dropped from group two to group three;
- o Greece dropped from group three to group four;
- o Croatia dropped from the fourth to the last group;
- o Austria advanced from group three to group two;
- o Slovakia advanced from group four to group three;
- o Slovenia advanced from the last group to the fourth.

The fourth variable is the *Nominal value of ICT exports of European countries* expressed in thousands of euros.³ Only the value of exports related to the digital economy (information and communication) to all countries in the world was used. The selection of the ICT sector is made in the same way as for the *Nominal value of ICT imports of European countries*.

ICT export

Table 5.5 shows the value of ICT imports in 2012–2019 for 25 European countries. Values are expressed in millions of euros and are adjusted for inflation.

The leaders in 2012 in ICT exports were the United Kingdom, Germany, the Netherlands, France and Spain. In 2019, the largest exports were recorded by: Germany, the Netherlands, the United Kingdom, Sweden and France. The

Table 5.5 Value of ICT sector exports in selected European countries in 2012–2019 (in EUR million)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	581.3237	664.3352	684.0139	995.7161	790.6507	744.0152	736.207	662.8305
Bulgaria	12.81817	16.77063	17.69538	28.9871	36.33757	58.94904	35.24181	42.97995
Czech Republic	79.03657	95.25155	106.2987	164.765	148.8421	154.5616	151.2556	165.8414
Denmark	410.924	430.8499	451.0163	453.9598	421.7398	411.8892	446.6922	407.0067
Germany	3787.662	3490.018	3611.187	3804.786	3946.862	3727.994	4965.611	4487.717
Estonia	31.91146	26.71923	23.06953	30.67965	39.50806	26.72898	20.21777	14.25754
Greece	286.4036	172.0952	157.6802	139.0726	126.4138	145.0871	112.8133	111.0664
Spain	829.2206	771.7221	883.5199	798.613	901.4834	969.6395	946.6443	916.0214
France	2255.876	1888.756	3816.244	4051.617	5288.285	4136.924	3907.2	1917.008
Croatia	41.61719	39.6707	43.90068	65.71534	64.34477	59.19173	65.48113	62.40103
Italy	578.6111	571.7501	570.6089	457.3901	360.4981	502.7663	585.9283	514.0844
Latvia	26.70045	19.50172	23.77728	21.46813	23.27927	29.1829	49.05457	58.30937
Lithuania	27.38462	26.19914	28.8737	43.07997	49.97288	51.23545	52.82672	69.97295
Hungary	106.6322	73.18153	86.08063	103.3715	129.8485	178.9796	78.505	112.92
Malta	0.10265	1.390349	2.071268	2.046707	1.663516	1.281916	1.260488	1.24186
Netherlands	2622.564	2556.105	3853.319	3628.732	2846.944	3194.678	4257.423	3997.365
Austria	289.4263	296.0319	297.7701	362.0339	360.6478	358.1591	432.2085	617.0101
Poland	370.9953	397.0711	390.4042	432.6338	481.6113	373.2563	375.2858	373.8895
Romania	80.95427	57.36093	56.04175	68.65487	73.13173	63.21504	72.21694	77.19912
Slovenia	40.65908	127.484	147.1113	155.2535	177.1284	218.761	282.6274	277.5511
Slovakia	182.3061	179.6119	238.8963	269.7975	221.1534	185.6235	168.2882	142.0019
Finland	110.4562	129.8685	158.2933	165.74	186.6356	176.0553	238.1238	296.2
Sweden	659.195	687.3101	697.8656	683.9618	4150.885	3183.81	2602.415	2361.952
Norway	200.722	196.7863	193.1171	189.3305	166.8923	208.1267	227.52	247.2877
United Kingdom	4732.11	4641.252	4272.798	4985.341	4240.456	3951.747	3969.332	3899.147

Source: Eurostat (n.d.); Database: EXT_TEC05.

smallest exports in 2012 were Malta, Bulgaria, Latvia, Lithuania and Estonia. In 2019, the smallest ICT exports were in Malta, Estonia, Bulgaria, Latvia and Croatia. The stability of the position of ICT export leaders such as Germany, the Netherlands, the United Kingdom and France reflects their strong position in the global ICT value chain and communications technologies. Sweden's entry into the top five exporters in 2019 may reflect its dynamic development of the ICT sector and effective innovation strategies. On the contrary, the consistently low value of exports in countries such as Malta, Estonia, Bulgaria, Latvia and now Croatia, indicates the smaller scale of their ICT sector or limited ability to compete in international markets.

The average value of exports increased from €733.82 million in 2012 to €873.33 million in 2019. The total value of ICT exports in the countries studied increased from €18.35 billion to €21.83 billion. The 19% increase in the average value of exports and the total value of ICT exports during the period under review demonstrates the growing importance of ICT and communications technologies in the global economy. This increase can be attributed to both the development of new technologies and the increase in demand for ICT products and services worldwide. This evolution underscores the importance of investing in innovation and development in the ICT sector to maintain and increase competitiveness in the global market.

The fastest export growth was recorded in Malta (1109.8%), Slovenia (582.63%), Sweden (258.31%), Bulgaria (235.3%) and Finland (168.16%). At the same time, there was a decline in ICT exports in real terms (adjusted for inflation) in 8 countries (Greece, Estonia, Slovakia, United Kingdom, France, Italy, Romania and Denmark). The spectacular growth of ICT exports in Malta, Slovenia, Sweden, Bulgaria and Finland may point to several key factors contributing to their success in this sector. For Malta, the growth of more than 1.100% is particularly impressive and may reflect effective government strategies to support innovation, technology and attract foreign investment. For Slovenia, Sweden, Bulgaria and Finland, significant increases may be the result of the development of specialized niches, investment in research and development and the effective use of the highly skilled nature of their technology workforces.

On the contrary, declines in ICT exports in real terms in countries such as Greece, Estonia, Slovakia, the United Kingdom, France, Italy, Romania and Denmark may indicate structural challenges, such as saturation of target markets, increasing international competition or changes in global value chains, which may have affected their ability to sustain export growth. For the United Kingdom and France, which are traditionally strong players in the ICT sector, the declines may also reflect the impact of external factors, such as political uncertainty or regulatory changes, on their export sectors.

Between 2012 and 2019, the standard deviation increased from 1252.11 to 1354.86, while the quarter deviation increased from 269.85 to 292.82. At the same time, the coefficient of variation based on standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 1.706 to 1.551. At the same time, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) fell from 1.344 to 1.055.

This means that from 2012 to 2019 the spread of performance relative to the average has narrowed – so there is a convergence in the performance of the variable for European economies. The decreasing value of the coefficient of variation based on quartile deviation indicates that the different quintile groups are less differentiated from each other.

Figure 5.4 shows quintile groups of ICT export volumes in 2012 and 2019 in selected European countries. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions are drawn from Figure 5.4:

- In the first quintile group in 2012 (taking values from EUR 0.69 billion to EUR 4.73 billion) were: Germany, Spain, France, the Netherlands and the United Kingdom. In 2019, the first quintile group (taking values from €1.12 billion to €4.49 billion) included, unchanged: Germany, France, the Netherlands, the United Kingdom and Sweden;
- In the second quintile group in 2012 (values from EUR 0.32 billion to EUR 0.69 billion) were: Belgium, Denmark, Italy, Poland and Sweden. In 2019, in the second quintile group (values from EUR 0.39 billion to EUR 1.12 billion) were: Spain, Belgium, Denmark, Italy and Austria;
- In the third quintile group in 2012 (values from EUR 108.93 million to EUR 322.05 million) were: Greece, Austria, Slovakia, Finland and Norway. In 2019, the third quintile group (values from €156.31 million to €387.14 million) included: Poland, Finland, Norway, Czech Republic and Slovenia;
- In the fourth quintile group in 2012 (values from EUR 38.91 million to EUR 108.93 million) were: Czech Republic, Croatia, Hungary, Romania and



Figure 5.4 ICT export value in 2012 and 2019.

Source: Own compilation based on Eurostat.

- Slovenia. In 2019, the fourth quintile group (values from €68.46 million to €156.31 million) included: Greece, Slovakia, Hungary, Romania and Lithuania;
- In the last quintile group in 2012 (values ranging from €0.1 million to €38.91 million) were: Bulgaria, Estonia, Latvia, Lithuania and Malta. In 2019, in the last quintile group (values from €1.24 million to €68.46 million) were: Croatia, Bulgaria, Estonia, Latvia and Malta;

From an analysis of Figure 5.4, we can infer country shifts between quintile groups:

- Croatia dropped from the fourth to the last group;
- Spain dropped from group one to group two;
- Poland dropped from group two to group three;
- Greece and Slovakia dropped from group three to group four;
- Sweden advanced from group two to group one;
- Austria advanced from group three to group two;
- The Czech Republic and Slovenia advanced from group four to group three;
- Lithuania advanced from the last group to the fourth.

The fifth variable is the *Share of companies employing ICT professionals*.⁴ The selection of the ICT sector is made in the same way as for the *Nominal value of ICT imports of European countries*.

Share of companies employing ICT specialists

Table 5.6 shows the percentage of companies that employed ICT specialists between 2012 and 2019 for 25 European countries.

The leaders in hiring ICT specialists in 2012 were the Czech Republic, Greece, Hungary, Austria and Finland. In 2019, the highest performance was in: Hungary, Finland, the United Kingdom, Belgium and Denmark. The lowest rates in 2012 were recorded in: Bulgaria, Poland, Estonia, France and Italy. In 2019, the lowest values were in Greece, Spain, Italy, Lithuania and Poland. Changes in the employment leaders of ICT professionals between 2012 and 2019 reflect dynamic transformations in the ICT labor market and communication technologies. The rise in the position of Hungary, Finland, the United Kingdom, Belgium and Denmark as the countries with the highest employment rate of ICT specialists may reflect the strong demand for highly skilled labor in these countries, reflecting the growing role of technology in their economies and effective educational and economic policies supporting the development of the ICT sector. Greece's drop to the group of countries with the lowest rate may also reflect the economic difficulties that have affected the ICT sector.

The spread of extreme results narrowed from 14 percentage points in 2012 to 12 percentage points in 2019. It is noteworthy that the share of companies employing ICT specialists fell from an average of 27.32% (2012) to 23.52% (2019). During the period under review, the lower limit of the observed performance of the

Table 5.6 Share of companies employing ICT specialists in selected European countries in 2012–2019 (in %)

Country	2012	2014	2015	2016	2017	2018	2019
Belgium	28	26	28	26	29	28	28
Bulgaria	13	21	20	20	19	20	20
Czech Republic	29	21	19	19	21	19	20
Denmark	27	27	24	25	24	28	30
Germany	21	22	21	22	19	20	19
Estonia	18	15	15	15	15	13	15
Greece	35	24	26	30	20	22	22
Spain	22	25	25	25	21	18	17
France	15	15	16	16	17	17	17
Croatia	21	20	22	17	20	20	19
Italy	14	15	17	17	16	16	16
Latvia	23	21	19	17	14	15	20
Lithuania	22	16	15	15	18	17	15
Hungary	30	27	26	26	27	26	26
Malta	26	26	26	26	24	24	27
Netherlands	26	27	28	26	27	27	25
Austria	31	24	24	25	23	20	20
Poland	14	10	12	12	12	13	23
Romania	4	12	13	11	10	11	10
Slovenia	21	20	20	20	19	20	18
Slovakia	25	18	19	20	20	18	18
Finland	33	28	25	24	26	26	26
Sweden	22	20	19	18	20	19	18
Norway	31	20	19	19	19	18	19
United Kingdom	30	24	22	23	22	24	27

Source: Eurostat (n.d.); Database: ISOC_SKE_ITSPEN2.

variable decreased (from 21% to 18%). The upper limit of the observed performance of the variable also fell from 35% to 30%. The decline in the average proportion of companies employing ICT specialists from 27.32% to 23.52% suggests that despite the overall digitization and the growing role of technology in the economy, a smaller proportion of companies chose to directly employ ICT specialists. This may reflect the outsourcing of ICT functions, automation or more efficient use of existing human resources.

In 2012, the above-average score was recorded in 13 countries, 5 of which were New Union countries. In 2019, an above-average score was also recorded in 13 countries, 6 of which were New Union countries. The constant number of countries with an above-average score, with a slight increase in the share of New Union countries in this group, indicates stability in the distribution of ICT talent in Europe, with a slight shift toward the New Union members, which may suggest the effectiveness of their educational and economic policies in the ICT sector.

The highest gains were in Bulgaria and Poland (up from 21% to 25%). There was also positive growth in Belgium, Denmark, Malta and the Netherlands (from

29% to 30%). At the same time, the rest of the countries observed saw a decline (the largest in Norway from 35% to 20%). The decline in Norway and other countries may suggest market oversaturation, changes in business models or challenges in sustaining job growth in a rapidly changing technology sector.

Between 2012 and 2019, the standard deviation fell from 7.344 to 4.839, while the quarter deviation fell from 4 to 35. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.316 to 0.235. At the same time, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) rose from 0.174 to 0.175.

This means that from 2012 to 2019 the spread of the value of the *Share of companies employing ICT specialists* has decreased, as can be inferred from the indicator based on the standard deviation. At the same time, the analysis of the quartile deviation and the variation index based on it indicates a greater differentiation of quintile groups relative to the median.

Figure 5.5 shows quintile groups of the share of companies employing ICT specialists in 2012 and 2019 in selected European countries. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions are drawn from Figure 5.5:

- In the first quintile group in 2012 (taking values from 30 to 35) are: Greece, Hungary, Austria, Finland, Norway and the United Kingdom. In 2019, in the first quintile group (taking values from 26 to 30) are: Hungary, Finland, the United Kingdom, Belgium, Denmark and Malta;
- In the second quintile group in 2012 (values from 26 to 30) were: Belgium, Czech Republic, Denmark, Malta and the Netherlands. In 2019, the second

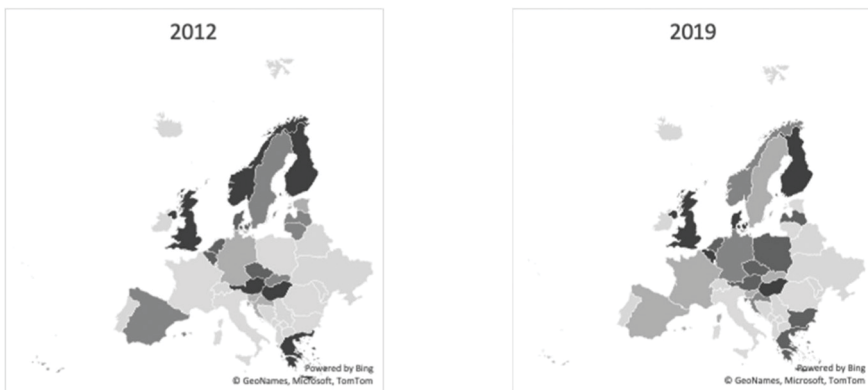


Figure 5.5 Share of companies employing ICT professionals in 2012 and 2019.

Source: Own compilation based on Eurostat.

quintile group (values from 20 to 26) included: Greece, Austria, Czech Republic, the Netherlands, Latvia, Bulgaria and Poland;

- In the third quintile group in 2012 (values from 22 to 26) were: Spain, Latvia, Lithuania, Slovakia and Sweden. In 2019, in the third quintile group (values from 19 to 20) were: Norway, Germany and Croatia;
- In the fourth quintile group in 2012 (values from 17.4 to 22) were: Germany, Estonia, Croatia and Slovenia. In 2019, in the fourth quintile group (values from 17 to 19) were: Spain, Slovakia, Sweden, Slovenia and France;
- In the last quintile group in 2012 (values from 4 to 17.4) are: Bulgaria, France, Italy, Poland and Romania. In 2019, in the last quintile group (values from 10 to 17) are: Lithuania, Estonia, Italy and Romania.

From an analysis of Figure 5.5, we can infer country shifts between quintile groups:

- o Greece and Austria dropped from group one to group two;
- o Norway dropped from group one to group three;
- o Spain, Slovakia and Sweden dropped from group three to group four;
- o Lithuania dropped from the third to the last group;
- o Estonia dropped from the fourth to the last group;
- o Belgium, Denmark and Malta advanced from group two to group one;
- o Latvia advanced from group three to group two;
- o Germany and Croatia advanced from group four to group three;
- o France advanced from the last group to the fourth;
- o Bulgaria and Poland were promoted from the last group to the second, which is the largest shift in the study group.

The sixth characteristic is Business Enterprise *Research and Development (R&D) Expenditures* (BERD) from the ICT sector relative to total R&D expenditures.⁵ The selection of the ICT sector is made in the same way as for the *Nominal value of ICT imports of European countries*.

Table 5.7 shows the percentage of ICT companies' R&D expenditures as a proportion of total expenditures from 2012 to 2019 for 25 European countries.

Spending by companies on R&D

Table 5.7 shows the percentage of ICT companies' R&D expenditures as a proportion of total expenditures from 2012 to 2019 for 25 European countries.

The leaders in ICT R&D expenditures in 2012 were Malta, Finland, Estonia, Norway and Greece. In 2019, the highest values were recorded in Malta, Estonia, Bulgaria, Finland and Croatia. The lowest values of the variable in 2012 were recorded in Bulgaria, Slovenia, the Netherlands, Germany and Austria. In 2019, Germany, Slovenia, the Netherlands, Denmark and Hungary had the lowest ICT R&D expenditures relative to the total. Data for Sweden for the entire period was unavailable. It is interesting to note that countries traditionally considered strong

Table 5.7 Share of ICT R&D expenditures in total R&D expenditures in selected European countries in 2012–2019 (in %)

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Belgium	14.15	13.77	13.325	13.085	14.47	14.98	15.85	17.59
Bulgaria	5.64	7.065	11.79	12.5	34.09	34.27	38.02	38.5
Czech Republic	15.99	15.44	17.87	17.99	19.23	19.69	21.2	21.21
Denmark	15.02	12.51	12.25	12.14	13.21	9.23	10.35	11.48
Germany	12.71	12.09	11.6	11.12	10.27	9.42	9.6	9.8
Estonia	31.44	37.23	39.925	44.8375	48.4725	44.71	55.15	49.74
Greece	24.3	24.3	25.515	26.88	25.35	23.72	22.975	22.19
Spain	13.89	14.4	14.92	13.82	14.07	12.77	14.03	13.92
France	17.34	18.41	18.82	18.8825	19.3	20.2	20.2	20.2
Croatia	21.96	21.39	20.53	17.765	15.855	20.275	28.2	30.19
Italy	18.2	18.61	15.88	16.925	16.64	16.38	16.22	16.69
Latvia	14.4	16.84	15.77	20.59	17.05	17.2	18.47	22.4
Lithuania	15.23	20.16	17.72	15.875	10.795	22.525	16.16	17.05
Hungary	19.46	21.01	22.29	9.745	8.735	9.7	12.19	12.81
Malta	40.84	51.535	50.47	49.865	51.27	52.43	52.21	50.43
Netherlands	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Austria	13.19	13.19	13.34	13.72	14.11	14.31	15.445	16.57
Poland	15.75	14.17	13.23	15.33	22.67	18.43	18.29	18.87
Romania	19.22	13.46	11.34	13.84	22.36	12.87	13.58	17.8
Slovenia	8.84	8.36	10.71	11.51	8.81	10.605	8.315	9.95
Slovakia	13.96	12.39	14.41	17.03	16.135	15.16	14.58	17.6
Finland	38.54	40.01	39.19	40.93	37.92	37.54	36.74	36.56
Sweden	-	-	-	-	-	-	-	-
Norway	24.47	24.99	24.83	26.69	28.45	28.88	29.12	29.26
United Kingdom	17.04	16.51	16.27	15.95	14.85	15.67	15.29	15.29

Source: Eurostat (n.d.); Database: ISOC_BDE15AR2.

economies, such as Germany, the Netherlands and Austria, were among those with the lowest ICT sector R&D spending relative to the total. This may suggest that these countries are directing their R&D resources to other industry sectors, or that they have already developed ICT sectors that are now less dependent on intensive R&D spending. The increase in outlays in countries such as Bulgaria and Croatia may be indicative of their desire to increase competitiveness by investing in cutting-edge digital technologies and research.

The spread of results among the countries surveyed increased during the period under review. In 2012, the highest (Malta, 40.84%) values were separated from the lowest (Bulgaria, 5.64%) by 35.2 percentage points. In 2019, the gap between the highest score (Malta, 50.43%) and the lowest (Germany, 9.8%) increased to 40.63 percentage points. This variation may reflect different national strategies in fostering innovation and technology and the different levels of maturity of ICT sectors in each country.

The overall level of R&D spending by the ICT sector (calculated as a share of total R&D spending) has been increasing over the period under review from an average of 18.4% to 21.92%. Above-average performance in 2012 was achieved in

8 countries, 5 of which were New Union countries. In 2019, above-average results were recorded in 8 countries of which 5 were New Union countries.

The highest growth was recorded in Bulgaria (by 5.83 percentage points), Estonia (0.58 percentage points) and Latvia (0.56 percentage points). At the same time, the share of ICT sector spending fell in 8 countries (Finland, Romania, Italy, Greece, United Kingdom, Germany, Denmark and Hungary). The significant increase in ICT R&D spending in Bulgaria, Estonia and Latvia indicates that these countries are investing heavily in the development of their technology sectors, presumably to increase their international competitiveness. This may also be a sign of effective policies that support innovation and economic development through technology. Declines in these investments in some countries may indicate challenges in maintaining the pace of innovation or increasing global competition, which requires new adaptation strategies for these countries.

Between 2012 and 2019, the standard deviation increased from 8.499 to 11.569, while the quarter deviation increased from 3.071 to 4.584. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) increased from 0.462 to 0.528. Over the same period, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) increased from 0.194 to 0.259.

This means that from 2012 to 2019, the dispersion of the value of BERD from the ICT sector relative to total R&D expenditures has increased by which the results of individual countries differ increasingly. At the same time, increasing variation based on quartile deviation indicates greater differentiation of quintile groups relative to the median.

Figure 5.6 shows quintile groups of the share of ICT R&D spending in R&D spending in 2012 and 2019 in selected European countries. The first quintile group,

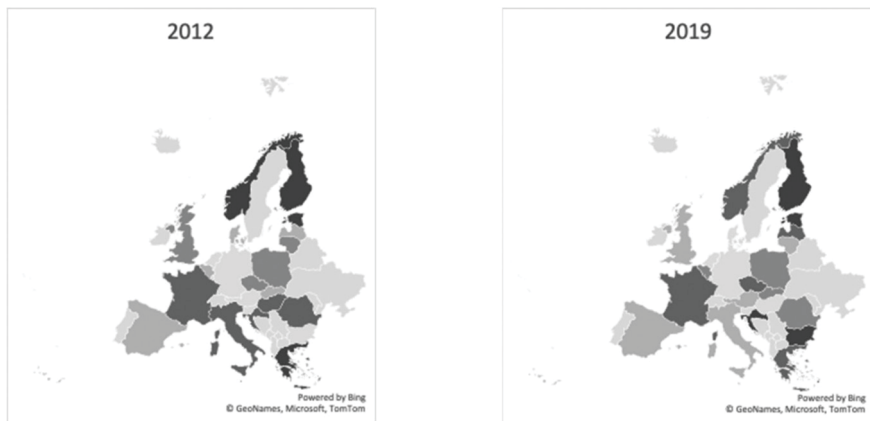


Figure 5.6 Share of ICT sector R&D expenditures in total R&D expenditures in 2012 and 2019.

Source: Own compilation based on Eurostat.

marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.6:

- In the first quintile group in 2012 (taking values from 22.9 to 40.84) were: Estonia, Greece, Malta, Finland and Norway. In 2019, in the first quintile group (taking values from 29.63 to 50.43) were: Estonia, Malta, Finland, Croatia and Bulgaria;
- In the second quintile group in 2012 (values from 17.28 to 22.9) were: France, Croatia, Italy, Hungary and Romania. In 2019, in the second quintile group (values from 19.93 to 29.63) were: Greece, Norway, France, the Czech Republic and Latvia;
- In the third quintile group in 2012 (values from 15.06 to 17.28) were: Czech Republic, Lithuania, Poland and the United Kingdom. In 2019, in the third quintile group (values from 17.16 to 19.93) were: Romania, Poland, Belgium and Slovakia;
- In the fourth quintile group in 2012 (values from 13.61 to 15.06) were: Belgium, Denmark, Spain, Latvia and Slovakia. In 2019, in the fourth quintile group (values from 13.48 to 17.16) were: Italy, Lithuania, United Kingdom, Spain and Austria;
- In the last quintile group in 2012 (values from 5.64 to 13.61) were: Bulgaria, Germany, the Netherlands, Austria and Slovenia. In 2019 in the last quintile group (values from 9.8 to 13.48) were: Hungary, Denmark, Germany, the Netherlands and Slovenia.

From an analysis of Figure 5.6, we can infer country shifts between quintile groups:

- Greece and Norway dropped from group one to group two;
- Romania dropped from group two to group three;
- Italy dropped from group two to group four;
- Lithuania and the United Kingdom dropped from group two to group four;
- Denmark dropped from the fourth to the last group;
- Hungary dropped from the second to the last group;
- Croatia advanced from group two to group one;
- The Czech Republic advanced from group three to group two;
- Latvia advanced from group four to group two;
- Belgium and Slovakia advanced from group four to group three;
- Austria advanced from the last group to the fourth;
- Bulgaria was promoted from the last group to the first, the largest shift in the period under review.

The seventh variable is *Value of online sales*, understood as the percentage of companies' sales turnover coming from online sales (e-commerce).⁶

E-commerce sales value

Table 5.8 shows the percentage of online sales to total business sales from 2012 to 2019 for 25 European countries.

The highest values in 2012 were in the Czech Republic, Sweden, Hungary, the United Kingdom and Finland. In 2019, the leaders were Belgium, the Czech Republic, Norway, Sweden and Denmark. In 2012, the lowest values were in Greece, Bulgaria, Romania, Italy and Latvia. In 2019, on the contrary, the lowest values were in: Greece, Bulgaria, Romania, Latvia and Italy. The entry of Belgium and Norway to the list of leaders in 2019, alongside countries such as the Czech Republic, Sweden and Denmark, may be indicative of effective e-commerce development strategies, investments in digital infrastructure and high levels of consumer confidence in online shopping in these countries. The continued positioning of the Czech Republic and Sweden among the leaders underscores their continued dominance and possible favorable regulatory environment, innovation and online shopping culture, which are conducive to e-commerce development. In contrast,

Table 5.8 Share of online sales in total sales of companies in selected European countries in 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	14	14	19.5	25	29	31	32	33
Bulgaria	3	3	3	5	4	5	5	4
Czech Republic	24	26	29	30	31	31	29	32
Denmark	17	17	17	20	23	23	23	25
Germany	17	14	13	17	14	21	14	15
Estonia	13	12	14	13	15	16	15	14
Greece	2	2	2	2	6	4	4	4
Spain	14	14	15	14	16	16	17	17
France	14	14	15	17	17	19	22	22
Croatia	11	11	13	14	14	11	12	12
Italy	6	7	7	9	9	10	11	12
Latvia	7	7	7	7	7	9	6	7
Lithuania	12	7	7	10	11	13	13	13
Hungary	19	16	20	19	16	20	23	24
Malta	13	13	9	11	13	12	13	14
Netherlands	13	13	12	13	14	15	15	14
Austria	13	12	13	16	15	14	14	14
Poland	10	11	12	13	14	15	15	18
Romania	4	6	6	8	7	8	9	7
Slovenia	13	11	12	13	15	16	17	17
Slovakia	12	17	16	21	18	22	21	21
Finland	18	16	19	21	21	21	21	23
Sweden	20	14	18	19	21	19	24	25
Norway	18	19	19	20	24	21	25	26
United Kingdom	19	18	20	20	19	18	19	21

Source: Eurostat (n.d.); Database: ISOC_EC_EVALN2.

the consistently low e-commerce sales in Greece, Bulgaria, Romania, Latvia and Italy throughout the period may reflect a number of challenges, such as limited Internet access, lower consumer confidence in online payments, regulatory barriers or limited investment in the e-commerce sector.

Between 2012 and 2019, the spread in e-commerce sales performance widened. In 2012, there was 22 percentage points between the highest score (Czech Republic, 24%) and the lowest (Greece, 2%). In 2019, the gap between the extremes (Belgium, 33%; Greece, 4%) has increased to 29 percentage points. This trend may reflect several factors, including differences in the speed of adoption of new technologies, the availability of digital infrastructure, the level of consumer confidence in online shopping, as well as government policies and initiatives supporting e-commerce development. On the one hand, countries such as Belgium, with the highest e-commerce sales values, may indicate a strong environment supporting online shopping, including high levels of Internet access, developed logistics and payment systems and effective marketing and sales strategies targeting digital consumers. On the other hand, persistently low figures in countries such as Greece, even despite growth, may suggest persistent structural and cultural barriers to faster e-commerce development. This includes limitations in digital infrastructure, lower levels of trust in online payment systems and shopping preferences leaning toward traditional retail.

The average share of online sales increased in the surveyed countries from 13.04% in 2012 to 17.36% of total sales in 2019. In 2012, an above-average result was recorded in 11 countries, 2 of which were New European Union countries (the Czech Republic and Hungary). In 2019, above-average results were also recorded in 11 countries, with 4 being New Union countries. The constant number of countries with above-average results, while the share of New Union countries increased from two to four, may indicate faster e-commerce adoption in these countries compared to their more developed neighbors. New Union countries, such as the Czech Republic and Hungary, maintaining their position above the average, as well as the addition of others, indicates the dynamic development of the e-commerce sector in these regions, which may be the result of effective investment strategies, policies supporting the development of digital entrepreneurship and the active use of European funds for the development of the digital economy.

Between 2012 and 2019, the largest increases in the role of online sales were recorded in Belgium (up 1.36 percentage points), Italy (up 1 percentage point) and Greece (up 1 percentage point). In contrast, the only country with negative growth in the role of e-commerce was Germany (down 0.12 percentage points).

Between 2012 and 2019, the standard deviation increased from 5.511 to 7.836, while the quarter deviation increased from 13.04 to 17.36. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) increased from 0.423 to 0.451. Over the same period, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) increased from 0.231 to 0.294.



Figure 5.7 Share of online sales in total company sales in selected European countries in 2012 and 2019.

Source: Own compilation based on Eurostat.

This means that from 2012 to 2019 the dispersion of *Online sales values* has increased which means greater differences between the analyzed countries. At the same time, the dispersion of the quintile group has increased.

Figure 5.7 shows quintile groups of the share of online sales in total business sales in 2012 and 2019 in selected European countries. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.7:

- In the first quintile group in 2012 (taking values from 18 to 24) were: Czech Republic, Hungary, Finland, Sweden, Norway and the United Kingdom. In 2019, in the first quintile group (values from 24.2 to 33) were: Czech Republic, Sweden, Norway, Belgium and Denmark;
- In the second quintile group in 2012 (values from 14 to 18) were: Belgium, Denmark, Germany, Spain and France. In 2019, in the second quintile group (values from 19.2 to 24.2) were: Hungary, Finland, the United Kingdom, France and Slovakia
- In the third quintile group in 2012 (values from 13 to 14) were: Estonia, Malta, the Netherlands, Austria and Slovenia. In 2019, in the third quintile group (values from 14 to 19.2) were: Germany, Spain, Estonia, Malta, the Netherlands, Austria, Slovenia and Poland;
- In the fourth quintile group in 2012 (values from 9.4 to 13) were: Croatia, Lithuania, Poland and Slovakia. In 2019, in the fourth quintile group (values from 12 to 14) were: Croatia, Lithuania and Italy;

- In the last quintile group in 2012 (values from 2 to 9.4) were: Bulgaria, Greece, Italy, Latvia and Romania. In 2019, in the last quintile group (values from 4 to 12) were: Bulgaria, Greece, Latvia and Romania;

From an analysis of Figure 5.7, we can infer country shifts between quintile groups:

- Hungary, Finland and the United Kingdom fell from group one to group two;
- Germany and Spain dropped from group two to group three;
- Belgium and Denmark advanced from group two to group one;
- Poland advanced from group four to group three;
- Italy advanced from the last group to the fourth;
- Slovakia was promoted from group four to group two, the largest shift in the period under review.

5.4 Group of demand-side variables

The first variable is the *Share of people using the Internet to interact with public authorities* who have used this method in the past 12 months. The data is collected by the National Statistical Offices and based on Eurostat's annual survey. The collected data on Internet users allows covering the growth of trust, digital competence and the use of digital services provided by state bodies.

Participation of Internet users in dealing with public authorities

Table 5.9 shows the percentage of people who used the Internet to contact public authorities from 2012 to 2019 for 25 European countries.

Denmark, Sweden, Norway, Finland and the Netherlands had the highest score in 2012. In 2019, the leaders were Denmark, Norway, Finland, Sweden and the Netherlands. Italy, Croatia, Bulgaria, the Czech Republic and Romania were the least likely to use e-government in 2012. In 2019, the smallest share of people using e-government was in Romania, Italy, Bulgaria, Croatia and Poland. The stability of the Nordic countries and the Netherlands among the leaders in the use of e-government in 2012 and 2019 underscores their leading role in the digitization of public services. Denmark, Norway, Finland, Sweden and the Netherlands are known for their high level of technological advancement and strong policies supporting the development of the information society.

Changes in the countries with the lowest share of e-government users, with Italy, Croatia, Bulgaria and Romania remaining among those with the lowest rates, and Poland joining this group in 2019, may indicate slower progress in the implementation of digital public services or lower citizen engagement in using such services. Reasons may include limitations in Internet access, a lack of digital skills among residents and possible shortcomings in designing and promoting e-services that are tailored to users' needs and expectations.

Table 5.9 People using the Internet to contact public authorities in selected European countries in 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	50	50	55	52	55	55	56	59
Bulgaria	27	23	21	18	19	21	22	25
Czech Republic	31	29	37	32	36	46	53	54
Denmark	83	85	84	88	88	89	92	92
Germany	51	49	53	53	55	53	57	59
Estonia	54	48	51	81	77	78	79	80
Greece	34	36	45	46	49	47	50	52
Spain	44	44	49	49	50	52	57	58
France	61	60	64	63	66	68	71	75
Croatia	26	25	32	35	36	32	36	33
Italy	19	21	23	24	24	25	24	23
Latvia	47	35	54	52	69	69	66	70
Lithuania	36	34	41	44	45	48	51	55
Hungary	42	37	49	42	48	47	53	53
Malta	41	32	41	42	45	46	47	50
Netherlands	67	79	75	75	76	79	82	81
Austria	53	54	59	57	60	62	66	70
Poland	32	23	27	27	30	31	35	40
Romania	31	5	10	11	9	9	9	12
Slovenia	48	52	53	45	45	50	54	53
Slovakia	42	33	57	51	48	47	51	59
Finland	70	69	80	79	82	83	83	87
Sweden	78	78	81	73	78	84	83	86
Norway	78	76	82	81	85	84	90	87
United Kingdom	43	41	51	49	53	49	59	63

Source: Eurostat (n.d.); Database: TIN00012.

During the period under study, an increasing spread in the performance of the analyzed countries can be seen. In 2012, between the highest score (Denmark, 83%) and the lowest (Italy, 19%) was 64 percentage points. In 2019, the highest score (Denmark 92%) and the lowest (Romania, 12%) were separated by 80 percentage points.

During the 2012–2019 period, an uplift in the overall average level of e-government use in European countries is evident. The average score of the analyzed countries rose from 47.52% to 59.04%. In 2012, an above-average result was achieved by 11 countries, of which 2 were New Union countries (Estonia and Slovenia). In 2019, 10 countries achieved an above-average result among which were 2 countries from the New Union (Estonia and Latvia).

The Czech Republic, Greece, Lithuania, Latvia, Estonia and the United Kingdom recorded the largest increases between 2012 and 2019. All of these countries increased their scores by more than 20 percentage points. Only 2 countries saw a regression in the use of e-government. In Bulgaria, the percentage fell by 2,

while in Romania by as much as 19. At the same time, between 2016 and 2018, Romania was the only country in the analyzed group where the percentage of use of e-government fell below the 10% level. This decline may indicate specific difficulties, such as limited Internet access, language barriers, lack of confidence in the e-services or insufficient promotional and educational activities aimed at citizens.

Between 2012 and 2019, the standard deviation increased from 17.333 to 21.181, while the quarter deviation increased from 10 to 11.5. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.365 to 0.359. Also, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) fell from 0.227 to 0.195.

This means that from 2012 to 2019, the dispersion of the value of the *Share of Internet users in interaction with public authorities* in the analyzed countries has decreased. There is a progressive convergence of European economies with regard to both the average and median values.

Figure 5.8 shows quintile groups of the share of people who use the Internet to contact public authorities in 2012 and 2019 in selected European countries. The first quintile group, marked in the darkest color, includes countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.8:

- In the first quintile group in 2012 (taking values from 62.2 to 83) were Denmark, the Netherlands, Finland, Sweden and Norway. In 2019, in the first quintile group (taking values from 80.2 to 92) were invariably Denmark, the Netherlands, Finland, Sweden and Norway;



Figure 5.8 People using the Internet to contact public authorities in 2012 and 2019.

Source: Own compilation based on Eurostat.

- In the second quintile group in 2012 (values from 48.8 to 62.2) were: Belgium, Germany, Estonia, France and Austria. In 2019, in the second quintile group (values from 60.6 to 80.2) were: Estonia, France, Austria, Latvia and the United Kingdom;
- In the third quintile group in 2012 (values from 42 to 48.8) were: Spain, Latvia, Hungary, Slovenia, Slovakia and the United Kingdom. In 2019, in the third quintile group (values from 54.6 to 60.6) were: Belgium, Germany, Spain, Slovakia and Lithuania;
- In the fourth quintile group in 2012 (values from 31.8 to 42) were: Greece, Lithuania, Malta and Poland. In 2019, in the fourth quintile group (values from 48 to 54.6) were: Hungary, Slovenia, Greece, Malta and the Czech Republic;
- In the last quintile group in 2012 (values from 19 to 31.8) were: Bulgaria, the Czech Republic, Croatia, Italy and Romania. In 2019, in the last quintile group (values from 12 to 48) were: Poland, Bulgaria, Croatia, Italy and Romania;

From an analysis of Figure 5.8, we can infer country shifts between quintile groups:

- Belgium and Germany dropped from group two to group three;
- Hungary and Slovenia dropped from group three to group four;
- Poland dropped from the fourth to the last group;
- Latvia and Great Britain advanced from group three to group two;
- Lithuania advanced from group four to group three;
- The Czech Republic advanced from the last group to the fourth.

The second variable is the *Share of people working remotely*, defined as the prevalence of remote working in European countries between 2012 and 2019.⁷

Number of people working remotely as % of employees

Table 5.10 shows the percentage of people who do their work remotely as a proportion of all employees from 2012 to 2019 for 25 European countries.

In 2012, Denmark, France, the Netherlands, Austria and Finland had the highest number of people working remotely. In 2019, the highest values were recorded in the Netherlands, Finland, Austria, Denmark and France. The least popular in 2012 was remote work in: Romania, Bulgaria, Croatia, Malta and Latvia. And in 2019, the lowest values were recorded in: Bulgaria, Romania, Hungary, Croatia and Greece. The stability among the remote work leaders, with countries such as Denmark, France, the Netherlands, Austria and Finland maintaining high positions in both 2012 and 2019, indicates these countries' strong commitment to promoting flexible forms of employment and adapting to modern working methods. Their success may be due to a combination of factors, such as advanced technological infrastructure, progressive approaches to management and organizational culture, as well as support for public policies and regulations that favor remote work. In addition, the data may signal where there may be spaces for further investment in

Table 5.10 People working from home as a proportion of all employees in selected European countries in 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	9.2	8.8	8.7	8.1	7.2	6.9	6.6	6.9
Bulgaria	0.5	0.5	0.4	0.3	0.2	0.3	0.3	0.5
Czech Republic	3.4	3.3	3.4	3.5	3.8	3.9	4.0	4.6
Denmark	11.7	11.0	9.9	9.0	8.4	8.8	7.8	7.8
Germany	3.5	3.3	3.2	3.3	3.2	4.8	5.0	5.2
Estonia	5.7	6.2	5.5	5.4	5.8	5.7	7.4	6.6
Greece	2.1	2.2	2.7	2.6	2.6	2.3	2.0	1.9
Spain	4.4	4.3	4.3	3.6	3.5	4.3	4.3	4.8
France	11.5	7.3	6.8	7.0	6.9	6.7	6.6	7.0
Croatia	0.9	1.0	1.4	1.2	1.4	1.4	1.4	1.9
Italy	3.3	3.1	3.2	3.4	3.3	3.5	3.6	3.6
Latvia	2.0	2.1	2.5	2.1	2.6	2.1	2.9	3.0
Lithuania	4.0	3.9	4.1	3.0	2.7	2.6	2.5	2.4
Hungary	3.1	3.9	3.4	3.4	3.0	2.5	2.3	1.2
Malta	1.8	2.2	2.7	2.6	3.6	4.4	5.8	6.1
Netherlands	11.5	12.6	13.1	13.6	13.4	13.7	14.0	14.1
Austria	10.3	10.4	10.7	10.2	9.9	9.5	10.0	9.9
Poland	4.6	4.0	4.6	5.6	5.3	4.5	4.6	4.6
Romania	0.4	0.3	0.4	0.5	0.5	0.4	0.4	0.8
Slovenia	6.6	7.1	7.7	7.9	7.5	7.2	6.9	6.8
Slovakia	3.5	3.5	3.5	3.2	3.2	3.5	3.6	3.7
Finland	9.8	10.6	10.6	12.0	11.9	12.3	13.3	14.1
Sweden	4.5	4.8	4.9	5.1	5.1	5.0	5.3	5.9
Norway	4.7	5.1	4.4	4.1	4.9	5.1	5.5	5.0
United Kingdom	3.5	3.4	3.6	3.8	4.1	4.0	4.4	4.7

Source: Eurostat [LFSA_EHOMP].

digital infrastructure and digital education to enable greater access to remote work and increase flexibility in the labor market

The spread of extreme scores in the countries surveyed increased during the period under review. The highest score in 2012 (Denmark, 11.7%) was separated from the lowest (Romania, 0.4%) by 11.3 percentage points. In 2019, the gap between the highest score (the Netherlands, 14.1%) and the lowest (Bulgaria, 0.5%) increased to 13.6 percentage points

Between 2012 and 2019, the average level increased from 5.06% to 5.32%. In 2012, an above-average result was recorded in 3 countries (Denmark, the Netherlands and France). In 2019, 2 countries (the Netherlands and Finland) had an above-average score. This indicates a moderate adaptation of remote work in the surveyed countries prior to the COVID-19 pandemic. This increase, although modest, reflects a growing trend among companies and employees to use digital technologies that enable work outside the traditional office. The reduction in the number of countries with above-average scores from three (Denmark, the Netherlands, France) in 2012 to two (the Netherlands and Finland) in 2019 may

suggest that there has been a slowdown in growth or stabilization in the level of remote work in some countries. This could be due to a variety of factors, such as saturation of the remote work market in these countries, constraints to further development of digital infrastructure or cultural or organizational barriers to adopting remote work on a larger scale.

The largest increases were recorded in Malta (by 4.3 percentage points), Finland (by 4.3 percentage points), the Netherlands (by 2.6 percentage points), Germany (by 1.7 percentage points) and Sweden (by 1.4 percentage points). Declines in the variable were recorded in: France (by 4.5 percentage points), Denmark (by 3.9 percentage points), Belgium (by 2.3 percentage points), Hungary (by 1.9 percentage points), Lithuania (by 1.6 percentage points), Austria (by 0.4 percentage points) and Greece (by 0.2 percentage points). The increase may also indicate a cultural shift in attitudes toward work, with more emphasis on work-life balance and productivity, and not necessarily on physical presence in the office.

Between 2012 and 2019, the standard deviation fell from 3.563 to 3.516, while the quarterly deviation increased from 1.75 to 1.9. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.704 to 0.66. Over the same period, the coefficient of variation based on the quarterly deviation (the quotient of the quarterly deviation and the median) fell from 0.438 to 0.396.

This means that from 2012 to 2019, the dispersion of the value of the *Share of people working remotely* in the analyzed countries has decreased. The progressive convergence of European economies can be seen in both the mean and median values.

Figure 5.9 shows the quintile groups of the share of people who do their work remotely relative to all employees in 2012 and 2019 in selected European countries.



Figure 5.9 Share of people working remotely in 2012 and 2019.

Source: Own compilation based on Eurostat.

The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.9:

- In the first quintile group in 2012 (taking values from 9.32 to 11.7) were: Denmark, France, the Netherlands, Austria and Finland. In 2019, in the first quintile group (taking values from 6.92 to 14.1) were invariably Denmark, France, the Netherlands, Austria and Finland;
- In the second quintile group in 2012 (values from 4.54 to 9.32) were: Belgium, Estonia, Poland, Slovenia and Norway. In 2019, in the second quintile group (values from 5.48 to 6.92) were: Belgium, Estonia, Slovenia, Sweden and Malta;
- In the third quintile group in 2012 (values from 3.5 to 4.54) were: Germany, Spain, Lithuania, Slovakia, Sweden and the United Kingdom. In 2019 in the third quintile group (values from 4.6 to 5.48) were: Poland, Norway, Germany, Spain, the United Kingdom and the Czech Republic;
- In the fourth quintile group in 2012 (values from 2.08 to 3.5) were: Czech Republic, Greece, Italy and Hungary. In 2019, in the fourth quintile group (values from 2.3 to 4.6) were: Lithuania, Slovakia, Italy and Latvia;
- In the last quintile group in 2012 (values from 0.4 to 2.08) were: Bulgaria, Croatia, Latvia, Malta and Romania. In 2019, in the last quintile group (values from 0.5 to 2.3) were: Greece, Hungary, Bulgaria, Croatia and Romania.

From an analysis of Figure 5.9, we can infer country shifts between quintile groups:

- Poland and Norway dropped from group two to group three;
- Lithuania and Slovakia dropped from group three to group four;
- Greece and Hungary dropped from the fourth to the last group;
- Sweden advanced from group three to group two;
- The Czech Republic advanced from group four to group three;
- Latvia advanced from the last group to the fourth;
- Malta was promoted from the last group to the second, the largest shift in the period under review.

The third variable is the *Share of e-commerce users*, defined as those who have used the Internet to purchase goods and services in the past 12 months, relative to the country's total population.⁸

Share of people using

Table 5.11 contains the percentage of people who used the Internet to purchase goods and services in the past year for 25 European countries between 2012 and 2019.

Table 5.11 Share of e-commerce users in selected European countries 2012–2019 (in %)

Country	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	45	48	54	55	57	60	61	66
Bulgaria	9	12	17	18	17	18	21	22
Czech Republic	33	36	43	45	47	56	59	64
Denmark	73	77	78	79	82	80	84	84
Germany	65	69	70	73	74	75	77	79
Estonia	23	23	49	59	56	58	61	68
Greece	20	25	26	32	31	32	36	39
Spain	30	32	37	42	44	50	53	58
France	57	59	62	65	66	67	67	70
Croatia	23	26	28	31	33	29	35	45
Italy	17	20	22	26	29	32	36	38
Latvia	27	32	34	38	44	46	45	47
Lithuania	20	26	26	32	33	38	43	48
Hungary	25	29	33	36	39	39	41	49
Malta	44	46	47	51	49	53	55	58
Netherlands	65	69	71	71	74	79	80	81
Austria	48	54	53	58	58	62	60	62
Poland	30	32	34	37	42	45	48	54
Romania	5	8	10	11	12	16	20	23
Slovenia	34	36	37	39	40	46	51	56
Slovakia	45	44	48	50	56	59	59	60
Finland	65	65	68	69	67	71	70	73
Sweden	74	73	75	71	76	81	78	82
Norway	76	73	77	76	78	77	79	82
United Kingdom	73	77	79	81	83	82	83	87

Source: Eurostat (n.d.); Database: TIN00096.

The leaders in 2012 were Norway, Sweden, Denmark, the United Kingdom and Germany. In 2019, the largest number of e-commerce users was in: the United Kingdom, Denmark, Norway, Sweden and the Netherlands. In 2012, the lowest values were recorded in: Romania, Bulgaria, Italy, Lithuania and Greece. In 2019, the lowest e-commerce popularity was in Bulgaria, Romania, Italy, Greece and Croatia. The stability of the Nordic countries (Norway, Sweden, Denmark) and the United Kingdom among the leaders in e-commerce use in 2012 and 2019 underscores their strong position in e-commerce. The inclusion of the Netherlands among the leaders in 2019 may reflect its increased investment in digital infrastructure and successful strategies to promote online commerce. Germany's steady presence in the top spot in 2012, followed by a shift to the Netherlands, may also indicate dynamic changes in consumer shopping preferences and the development of e-commerce platforms and marketing strategies.

In the 2012–2019 period under study, the spread of extreme results decreased in the analyzed countries. In 2012, between the highest score (Norway, 76%) and the lowest (Romania, 5%), the difference was 71 percentage points. In 2019,

the gap between the highest score (the United Kingdom, 87%) and the lowest (Bulgaria, 22%) has narrowed to 65 percentage points. This trend is indicative of the increasing digitization of economies and a greater unification of the level of e-commerce development in Europe, which may be due to better access to the Internet, increased confidence in online shopping and improved logistics and digital infrastructure.

Between 2012 and 2019, the average level of e-commerce use increased from 41.04% to 59.8%. In 2012, the above-average result was recorded in 12 countries, of which 2 were New Union countries. In 2019, an above-average result was achieved by 13 countries, 3 of which were New Union countries. The significant increase in the popularity of e-commerce underscores how digital technology and the Internet are changing shopping behavior, making e-commerce an increasingly important part of the retail market. The increase in the number of countries achieving an above-average score, from 12 in 2012 to 13 in 2019, including an increase in the number of New Union countries from 2 to 3, shows that e-commerce development is no longer reserved for only the most developed economies

The largest growth between 2012 and 2019 was recorded in Estonia (up 45 percentage points), the Czech Republic (up 31 percentage points), Spain (up 28 percentage points), Lithuania (up 28 percentage points), Poland (up 24 percentage points), Hungary (up 24 percentage points), Slovenia (up 22 percentage points), Croatia (up 22 percentage points), Belgium (up 21 percentage points), Italy (up 21 percentage points) and Latvia (up 20 percentage points). At the same time, no country saw a decline in the percentage of people using e-commerce during the period under review.

Between 2012 and 2019, the standard deviation fell from 22.05 to 18.166, while the quarter deviation fell from 21 to 12.5. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.537 to 0.304. Similarly, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) fell from 0.618 to 0.208.

This means that from 2012 to 2019, the dispersion of the value of the *Share of people using e-commerce* in the analyzed countries has decreased. The progressive convergence of European economies can be seen in both the mean and median values.

Figure 5.10 shows quintile groups of the share of people who used the Internet to purchase goods and services in the past 12 months, relative to the total population in 2012 and 2019 in selected European countries. The first quintile group, marked in the darkest color, includes countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.10:

- In the first quintile group in 2012 (taking values from 65 to 76) were: Denmark, Germany, the Netherlands, Finland, Sweden, Norway and the United Kingdom. In



Figure 5.10 Share of people using e-commerce in 2012 and 2019.

Source: Own compilation.

- 2019, the first quintile group (taking values from 79.4 to 87) included: Denmark, the Netherlands, Sweden, Norway and United Kingdom;
- In the second quintile group in 2012 (values from 45 to 65) were: Belgium, France, Austria and Slovakia. In 2019, in the second quintile group (values from 64.8 to 79.4) were Germany, Finland, Belgium, France and Estonia;
 - In the third quintile group in 2012 (values from 30 to 45) were: Czech Republic, Spain, Malta, Poland, Slovenia. In 2019, in the third quintile group (values from 57.2 to 64.8) were: Austria, Slovakia, Czech Republic, Spain and Malta;
 - In the fourth quintile group in 2012 (values from 22.4 to 30) were: Estonia, Croatia, Latvia and Hungary. In 2019, in the fourth quintile group (values from 46.6 to 57.2) were: Poland, Slovenia, Latvia, Hungary and Lithuania;
 - In the last quintile group in 2012 (values from 5 to 22.4) were: Bulgaria, Greece, Italy, Lithuania and Romania. In 2019, in the last quintile group (values from 22 to 46.6) were: Croatia, Bulgaria, Greece, Italy and Romania.

From an analysis of Figure 5.10, we can infer country shifts between quintile groups:

- Germany and Finland dropped from group one to group two;
- Austria and Slovakia dropped from group two to group three;
- Poland and Slovenia dropped from group three to group four;
- Croatia dropped from the fourth to the last group;
- Lithuania advanced from the last group to the fourth;
- Estonia was promoted from group four to group two, the largest shift in the period under review.

The fourth variable describes the *Share of people who use online banking*, defined as the percentage of people who have used the Internet to access online and mobile banking services in the past 12 months.⁹

Share of population using online banking

Table 5.12 contains the share of people who have used online banking services from 2012 to 2019 for 25 European countries.

The leaders in 2012 were Norway, Finland, the Netherlands, Denmark and Sweden. In 2019, the most popular use of online banking was in: Norway, Finland, the Netherlands, Denmark and Sweden. Both the countries and their order did not change for the 7-year period of the survey. In 2012, the lowest values were in Romania, Bulgaria, Greece, Croatia and Italy. In 2019, on the contrary, the lowest values were in: Romania, Bulgaria, Greece, Italy and Croatia. The only change among the lowest values was in the places of Italy and Croatia. The stability of the leaders in the use of online banking (Norway, Finland, the Netherlands, Denmark

Table 5.12 Share of people using online banking in selected European countries in 2012–2019 (in %)

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Belgium	56	58	61	62	64	67	69	71
Bulgaria	4	5	5	5	4	5	7	9
Czech Republic	35	41	46	48	51	57	62	68
Denmark	79	82	84	85	88	90	89	91
Germany	45	47	49	51	53	56	59	61
Estonia	68	72	77	81	79	79	80	81
Greece	9	11	13	14	19	25	27	31
Spain	31	33	37	39	43	46	49	55
France	54	58	58	58	59	62	63	66
Croatia	21	23	19	33	38	33	41	46
Italy	21	22	26	28	29	31	34	36
Latvia	47	55	57	64	62	61	66	72
Lithuania	43	46	54	50	54	56	61	65
Hungary	26	27	31	34	35	38	41	47
Malta	41	43	45	47	47	50	51	54
Netherlands	80	82	83	85	85	89	89	91
Austria	45	49	48	51	53	57	58	63
Poland	32	32	33	31	39	40	44	47
Romania	3	4	4	5	5	7	7	8
Slovenia	28	32	32	34	35	39	42	47
Slovakia	40	39	41	37	45	51	50	55
Finland	82	84	86	86	86	87	89	91
Sweden	79	82	82	80	83	86	84	84
Norway	86	87	89	90	91	92	93	95
United Kingdom	52	54	57	58	64	68	74	78

Source: Eurostat (n.d.); Database: ISOC_BDE15CBC.

and Sweden) for seven years indicates the continued strength of these countries in the digitization of financial services and the high level of trust and adoption of digital technologies by their citizens. The change in places between Italy and Croatia among the countries with the lowest values of online banking usage is minimal, but may reflect differences in the rate of online banking adoption, investment in digital infrastructure or changes in consumer behavior.

Between 2012 and 2019, the spread of extreme scores increased. In 2012, there was a difference of 83 percentage points between the highest (Norway, 86%) and lowest score (Romania, 3%). In 2019, the highest score (Norway, 95%) and the lowest score (Romania, 8%) were already separated by 87 percentage points. This increase, while indicating an overall improvement in access to online banking services, also underscores that technological advances and digital adaptation are evolving at different rates in each country.

During the period under review, the average use of online banking in the countries analyzed increased from 44.28% to 60.48%. In 2012, an above-average result was achieved by 12 countries, of which 2 were New Union countries. In 2019, an above-average result was achieved by 14 countries, of which 4 were New Union countries. The trend toward the digitization of personal finances and the growing acceptance of and trust in online transactions among consumers is evident.

The Czech Republic (up 33 percentage points), the United Kingdom (up 26 percentage points), Latvia (up 25 percentage points), Croatia (up 25 percentage points), Spain (up 24 percentage points), Lithuania (up 22 percentage points), Greece (up 22 percentage points) and Hungary (up 21 percentage points) saw the biggest advances between 2012 and 2019. At the same time, no country recorded a decline in the percentage of people using online banking during the period studied. The lack of decline in any country underscores that online banking is an increasingly well-established and indispensable tool in everyday life. For countries with lower usage rates, there is a clear need to further promote access to digital services, financial and digital education, and investment in digital security to increase trust and adoption of online banking.

Between 2012 and 2019, the standard deviation fell from 24.504 to 23.589, while the quarter deviation increased from 14 to 15.5. At the same time, the coefficient of variation based on the standard deviation (the quotient of the standard deviation and the arithmetic mean) fell from 0.553 to 0.39. At the same time, the coefficient of variation based on the quarter deviation (the quotient of the quarter deviation and the median) fell from 0.326 to 0.246.

This means that from 2012 to 2019, the dispersion of the value of the *Share of people using online banking* in the analyzed countries has decreased. The progressive convergence of European economies can be seen in both the mean and median values.

Figure 5.11 shows quintile groups of the share of people who have used the Internet to purchase goods and services in the past 12 months, relative to the total population in 2012 and 2019 in selected European countries. The first quintile group, marked in the darkest color, includes countries with the highest value of the

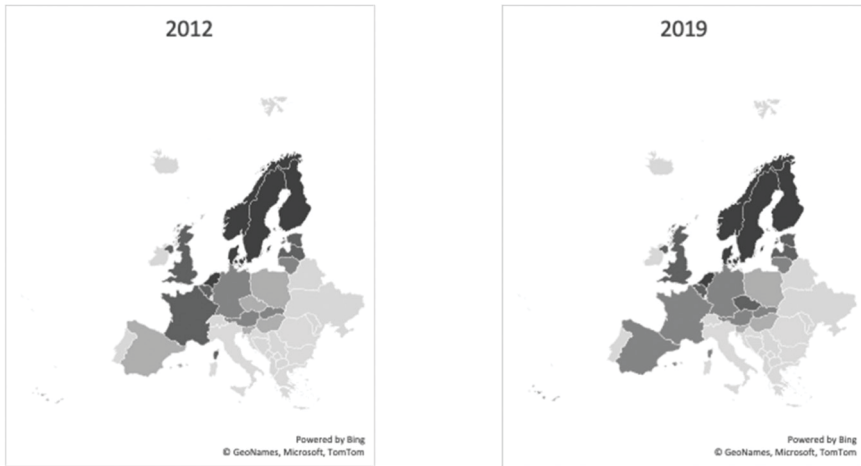


Figure 5.11 Share of people using online banking in 2012 and 2019.

Source: Own compilation based on Eurostat.

studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

The following conclusions can be drawn from Figure 5.11:

- In the first quintile group in 2012 (taking values from 70.2 to 86) were: Denmark, the Netherlands, Finland, Sweden and Norway. In 2019, Denmark, the Netherlands, Finland, Sweden and Norway were consistently in the first quintile group (taking values from 81.6 to 95);
- In the second quintile group in 2012 (values from 45.8 to 70.2) were: Belgium, Estonia, France, Latvia and the United Kingdom. In 2019, in the second quintile group (values from 66.8 to 81.6) were: Belgium, Estonia, Latvia, the United Kingdom and the Czech Republic;
- In the third quintile group in 2012 (values from 38 to 45.8) were: Germany, Lithuania, Malta, Austria and Slovakia. In 2019, in the third quintile group (values from 55 to 66.8) were: France, Germany, Lithuania, Austria, Slovakia and Spain;
- In the fourth quintile group in 2012 (values from 25 to 38) were: Czech Republic, Spain, Hungary, Poland and Slovenia. In 2019, in the fourth quintile group (values from 46.8 to 55) were: Malta, Hungary, Poland and Slovenia;
- In the last quintile group in 2012 (values from 3 to 25) were: Bulgaria, Romania, Greece, Croatia and Italy. In 2019, in the last quintile group (values from 8 to 46.8) were: Bulgaria, Greece, Croatia, Italy and Romania.

From an analysis of Figure 5.11, we can infer country shifts between quintile groups:

- The composition of the first and last groups did not change between 2012 and 2019;
- Malta dropped from group three to group four;
- France dropped from group two to group three;
- The Czech Republic advanced from group four to group two;
- Spain advanced from group four to group three.

5.5 Summary

The study conducted in this chapter leads to the following conclusions. In the group of supply-side variables, the following were analyzed: the share of ICT specialists in total employment, the share of the ICT sector in GDP, ICT imports and exports, the share of companies employing ICT specialists, ICT companies' R&D expenditures and the value of e-commerce sales. There is some danger in analyzing absolute values in the form of ICT imports and exports and e-commerce sales value. A possible solution to it would be to modify the variables by dividing them by total imports/exports, GDP, country population or labor force size.

Between 2012 and 2019, the values of all analyzed characteristics, except ICT imports, increased. In three cases there was an increase in the spread of extreme results (share of ICT specialists in total employment, ICT sector R&D expenditures, e-commerce sales). An almost equal share of New and Old Union countries among the leaders of the analyzed variables is evident. Eastern European countries with above-average values were Estonia, Latvia, Hungary and Malta. The apparent division of Europe in the traditional sense is only in ICT imports and exports – this is also the only pair of variables in nominal rather than percentage terms. In this case, the size of the nominal economies of Germany or France outclasses those of Estonia or Malta. At the same time, the weak growth rate of the digital economies of Italy, Greece and Spain is apparent, which may indicate a lowering of their development potential

In the group of demand variables, the share of people using the Internet to interact with public authorities, the share of people working remotely, the share of people using e-commerce and the share of the population using online banking were analyzed.

In 2012–2019, an increasing disparity among the surveyed countries (use of e-government, online banking, share of remote workers) is evident for three variables. At the same time, an increase in the average level of the variables is evident in the analysis of all characteristics

In the case of demand-side variables, the traditional division of Europe¹⁰ is evident – among the leaders of the analyzed values of the variables we will not find the countries of the New Union. At the same time, one can see a large representation of these countries among those with the highest dynamics of change between 2019 and 2012 – here the largest increases were achieved by the Czech Republic, Lithuania, Estonia, Latvia, Hungary and Croatia.

Several countries saw a regression in the values of the variables between 2012 and 2019:

- Bulgaria and Romania (use of e-government);
- France, Denmark, Belgium, Hungary, Lithuania, Austria and Greece (remote work);
- Spain, Italy, Denmark, Slovakia and Malta (ICT share of GDP);
- Finland, Romania, Italy, Greece, United Kingdom, Germany, Denmark and Hungary (ICT sector R&D spending).

In terms of the second and fourth hypotheses, an interesting issue is the potential complementarity or delayed impact of digitization on human capital (supply variables on demand variables), which could explain the presence among the leaders of the supply variables of numerous countries of the New Union and their simultaneous absence in the case of demand variables. An important question in this case becomes the question of how to maintain the dynamic development of Eastern European countries in the long term, which would enable the further course of the European economy.

Notes

- 1 This figure includes working owners, permanent associates, unpaid family workers and people working outside the unit but owned and paid by it (sales representatives, suppliers, repair crews). At the same time, the collection does not include labor supplied to the unit by other enterprises, persons performing repair and maintenance work in the research unit on behalf of other enterprises, as well as those performing compulsory military service.
- 2 The value of traded goods is calculated at the country's border, on a CIF (cost, insurance, freight) basis. Thus, only contingencies (freight, insurance) incurred in the part of the transit located outside the territory of the country where the goods are imported are taken into account.
- 3 The value of traded goods is calculated at the country's border, on a free on board (FOB) basis. Thus, only contingencies (freight, insurance) incurred in the part of the transit located in the territory of the country from which the goods are exported are taken into account.
- 4 Indicates the percentage of companies with digital specialists in relation to the total self-employed and companies with 10 or more employees.
- 5 R&D activities include creative and systematic work undertaken to increase the stock of knowledge – including knowledge of humanity, culture and society – and to develop new applications of available knowledge.
- 6 Enterprises with 10 or more employees and the self-employed are analyzed. The variable is based on the annual turnover of enterprises from all sectors except the financial sector.
- 7 The variable used indicates the percentage of the population between the ages of 15 and 64 who perform their work duties from home. The measure of the prevalence of remote work includes only those who are employed and those who declared the frequency of remote work as “usually” (usually) in the survey. Thus, the prevalence of jobs that can perform their duties from home to a dominant degree and not just occasionally is apparent. The variable is derived from the Labour Force Survey (LFS), a survey targeting households to obtain information on the labor market and related issues through a series of personal interviews. The survey covers all citizens living in private households and excludes people in collective households such as boarding houses, dormitories and

hospitals. The definitions used are common to all EU member states and are based on international recommendations of the International Labor Organization (ILO).

- 8 This is the share of people who have used the Internet in the past 12 months. The data is collected by the National Statistical Offices and based on Eurostat's annual survey. The collected data on Internet users allows to cover the growth of trust, digital competence and use of digital services provided by state bodies.
- 9 The data is collected by the National Statistical Offices and based on Eurostat's annual survey. The collected data on Internet users allows covering the growth of trust, digital competence and use of digital services provided by state and private bodies.
- 10 Traditional division of Europe – refers to the division between the richer and poorer parts of Europe, which is evident using GDP per capita (PPP).

6 Level of digital saturation of EU economies

Presentation of results

6.1 Introduction

Schumpeter's theory points to the leading role of innovation in generating economic growth. Macroeconomic data to date suggests that the digital economy is slipping out of the framework Schumpeter laid out. The decline in productivity growth currently observed in European countries, with a high rate of development of the digital economy (after reports of international organizations OECD 2019, World Bank 2021b), contradict the positive impact of innovation on economic growth. The expected jump in productivity growth, which could be the expected effect of the new sectors and industries developed since the 1990s centered around the Internet, is not visible.

In this context, it becomes necessary to understand the reasons for the observed state of affairs, in particular, the determinants of the development of the digital economy and their relationship to economic growth in the digital age. This will help identify the main blockages to development and create economic policy tools that will improve the dynamics of economic growth, while avoiding the secular stagnation barded by skeptics of digitization (Summers, 2013).

For the purpose of verifying the hypotheses and answering the research questions, the concept of the digital economy is operationalized and narrowed down to the notion of "digital saturation of the industrial economy", that is, the measure by which digital transformation penetrates the structures of the traditional economy. This is defined by assessing the extent of digital use, the availability of qualified digital experts and the contribution of the ICT sector to value-added and trade. This makes it possible to assess the rate of development of this phenomenon and to compare different economies in terms of their degree of sophistication and digital economy.

The purpose of this chapter is to establish the properties of the relationship between digital transformation and economic growth using a variational econometric model explaining labor productivity.

The chapter is structured in three parts. In the first part, a review of neoclassical economic growth models is presented, in order to select the tool best suited to the study of digital transformation. Next, the process of creating a taxonomic index of digital saturation is described, using the variables selected and described

in Chapter 5. The values of this index are analyzed spatially and temporally for the entire European Union and for the four analytical groups. The chapter concludes with a multivariate study using a modified production function used in a selected economic growth model.

This chapter presents two variants describing economic growth using digital saturation, human capital and physical capital. The variants are based on the modified production function used in the Nonneman-Vanhoudt (1996) growth model. The study takes into account the size and structure of enterprises.

The developed taxonomic index of digital saturation was used to rank the studied European countries from the best to the least developed in terms of the digital economy, capturing the dynamics of change in the analyzed group. This fits in with the verification of the first hypothesis of a different division of Europe from the traditional one (by GDP), based on digitization. The taxonomic indicator was also used to indicate large differences in the level of development of the digital economy within groups of countries with similar levels of traditional development. The authors also ranked European countries by GDP per capita (traditional division), human capital and digital economy (taxonomic index of digital saturation). This made it possible to verify hypothesis two, regarding the complementarity of the digital economy and human capital.

The modified production function was used to answer three research questions and verify the fourth hypothesis. The first variant takes into account 12 variables describing the digital economy and physical and human capital. Parameter values estimated using it make it possible to come closer to answering the question of the digital economy's fulfillment of Schumpeterian creative destruction (question one) and to estimate the rate of technical progress characteristic of secular stagnation (question two). Variant two of the model (extended to include the size structure of enterprises) further verifies the fulfillment of the assumption of structured capitalism (question one). The models also serve to select the most significant drivers of economic growth, which is important for the creation of digitization policies and innovation (question three). In addition, the model will assign a leading role to the supply side of digitization (understood as creating infrastructure, conducting research and developing new products) or the demand side (social acceptance of new technologies and their use), which is a verification of hypothesis four.

6.2 Neoclassical production function

The production function is a key tool in economics for describing the relationship between factors of production (such as labor, capital and land) and the product produced. It represents the amount of a good or service that can be produced with given resources and technology. In neoclassical economics, the production function often takes a mathematical form allowing precise modeling of and analysis of production processes and enterprise decisions.

The genesis of the production function dates back to the work of classical economists such as Adam Smith, who noted the importance of the division of labor for productivity growth. The development of value theory by David Ricardo and

Thomas Malthus also contributed to the understanding of the role of factors of production. However, it was the marginal revolution and the work of economists such as William Stanley Jevons, Carl Menger and Léon Walras in the late 19th and early 20th centuries that laid the foundation for the modern understanding of the production function, emphasizing marginal change and its impact on economic decisions.

The neoclassical production function is based on several key assumptions. In addition, diminishing marginal returns are usually assumed, meaning that adding more units of one factor of production while keeping other factors at a constant leads to decreasing output growth. Factor substitutability is also an important assumption, although the degree of substitutability can vary depending on the specific production function.

The production function is widely used in economic analysis, from modeling corporate decisions, to analyzing economic growth, to studying the impact of technology on production. It makes it possible to quantify the impact of various factors on production efficiency, which is crucial for firm theory, economic policy and efficiency research.

Despite its widespread use, the production function also faces criticism. It is accused of being abstract in nature that ignores the direct impact of progress in analyses of production in the short term, which may inadequately reflect its dynamics and innovation. Critics also point to a problem with modeling certain types of production, especially those where the relationships between factors of production are more complex or where intangible factors such as knowledge and skills play important roles.

Initially, the production function was viewed in a very general sense as a way of describing the relationship between factors of production (such as labor, capital and land) and outputs in the form of products or services. This general concept was used by classical economists such as Adam Smith, David Ricardo and John Stuart Mill, who focused on labor, land and capital as the main factors of production, but did not formulate their theories in strict mathematical terms.

The marginalist revolution at the turn of the 20th century marked a turning point that introduced a new approach to economic analysis, focusing on marginal change and its impact on economic decisions. Economists such as William Stanley Jevons, Carl Menger and Léon Walras contributed to the development of marginalism, which significantly influenced the formation of neoclassical economics. In the context of the production function, it was marginalism and neoclassical economics that brought the formalization of production relations.

This transition was fundamental to economics, as it enabled more accurate modeling and understanding of production processes. The neoclassical production function became the basis for analyzing production efficiency, optimizing resource allocation and understanding the impact of technology and innovation on economic growth. Through the use of mathematical and statistical tools, economists were able to more accurately predict economic behavior and influence the formulation of economic policies.

The neoclassical production function in macroeconomics is defined by the function F , which represents the relationship between the factors of production – traditionally understood as capital K and labor L – and the product produced Y . An extension of the traditional neoclassical production function with additional

factors of production, such as human, social, relational, infrastructural and digital capital, is justified by the changing conditions and requirements of the modern economy. Technological and social developments have highlighted the importance of investing in intangible capital, which is becoming a key element in economic growth and innovation. Human capital, which includes the skills, knowledge and experience of employees, is the basis for increasing the productivity and efficiency of production processes. Social capital, reflecting the quality of social relationships and networks, influences the diffusion of knowledge and innovation. Relational capital emphasizes the importance of long-term business relationships and customer loyalty. Infrastructure, both physical and digital, enables the efficient exchange of information and goods, while digital capital, including ICT, is a catalyst for digital transformation and new business models. Incorporating these factors into the analysis allows for a better understanding of the mechanisms of growth in a knowledge- and technology-based economy, which is essential for the formulation of sound economic policies and business development strategies. With the above in mind, the production function can be written using the following equation

$$Y = F(K_1, K_2, K_3, \dots, K_n, L) \tag{6.1}$$

Where:

K_i is the input of the i -th capital stock, while L is the input of labor, for the $i = 1, \dots, n$

About this function (1) it is assumed that:

1. The domain D_F of the function F includes all nonnegative inputs of consecutive capital $K_1, K_2, K_3, \dots, K_n$ and labor L , so $D_F = [0, +\infty)^{n+1}$.
2. The function F is at least twice differentiable, with the second derivative being a continuous function.
3. For each set of inputs $(K_1, K_2, K_3, \dots, K_n, L) \in D_F$ occurs:

$$F(0, K_2, K_3, \dots, K_n, L) = \dots = F(K_1, \dots, 0, \dots, K_n, L) = F(K_1, K_2, K_3, \dots, K_n, 0) = 0 \tag{6.2}$$

This assumption is economically interpreted as requiring both capital inputs K_i of various types and labor inputs L to produce any positive output Y . The absence of either of these factors of production makes the production process impossible, which emphasizes their interdependence and indispensability in the creation of a product.

4. The function F is homogeneous of degree one with respect to the inputs of both capital and labor, which is the same as the fact that there are constant returns to scale in the production process of the economy.

5. Let $MPK_i = \frac{\partial Y}{\partial K_i} = \frac{\partial F}{\partial K_i}$ and $MPL = \frac{\partial Y}{\partial L} = \frac{\partial F}{\partial L}$ denote the marginal product of capital (MPK_i) and the marginal product of labor (MPL), respectively. For each $K_i > 0$ and $L > 0$, the relationships are assumed: $MPK_i > 0$ and $MPL > 0$, meaning that any positive combination of capital or labor inputs contributes to the generation of positive marginal products of these factors of production. This property emphasizes the productive nature of all factors in the production of goods and services.
6. The production function is characterized by the fact that (for $i = 1, \dots, n$) with very large inputs of capital K_i or labor L – assuming that the second of these factors is not zero – the volume of production Y grows indefinitely, aiming at $+\infty$. This assumption, expressed by:

$$\forall K_1, K_2, K_3, \dots, K_n, L > 0$$

$$\lim_{K_i \rightarrow +\infty} F(K_1, K_2, K_3, \dots, K_n, L) = \lim_{L \rightarrow +\infty} F(K_1, K_2, K_3, \dots, K_n, L) = +\infty \quad (6.3)$$

shows that an unlimited increase in the input of one factor at a constant level of the others leads to an unlimited increase in output.

7. The so-called Inada conditions are also satisfied, which can be written as follows (for $i=1, \dots, n$):

$$\forall K_i, L > 0 \lim_{K_i \rightarrow 0^+} MPK_i = +\infty \quad (6.4)$$

$$\forall K_i, L > 0 \lim_{K_i \rightarrow +\infty} MPK_i = 0 \quad (6.5)$$

$$\forall L, K_i > 0 \lim_{L \rightarrow 0^+} MPL = +\infty \quad (6.6)$$

$$\forall L, K_i > 0 \lim_{L \rightarrow +\infty} MPL = 0 \quad (6.7)$$

Inada conditions describe the behavior of the marginal product of capital (MPK_i) and labor (MPL) at extreme values of inputs. At low capital inputs, MPK_i reaches high values, which means that a small increase in capital inputs can increase output significantly. Conversely, at high capital inputs MPK_i is low, indicating the law of diminishing returns. Similarly, with very little labor input, MPL is high, suggesting that an increase in labor input will significantly increase output, but this effect diminishes as labor input increases. These conditions underscore the need to balance capital and labor for production efficiency.

An increase in the input of one factor of production – capital or labor – while keeping the input of another factor unchanged leads to a decrease in the marginal product of the factor in question. At the same time, with a constant quantity of the other factor, the curve of the relationship between the quantity of output and the input of the factor in question is concave. This flows directly from the assumptions imposed on the production function, which imply the law of diminishing marginal productivity for all factors of production. The economic interpretation of this law is that with increasing inputs of one of the factors, the increase in output becomes smaller and smaller and the marginal product of this factor decreases.

The Cobb-Douglas production function is a classical production function in economic theory, introduced in 1928, which is a special case of the general neoclassical production function (Tokarski, 2009). The production function can be written using the following equation

$$\forall K, L \geq 0 \quad Y = F(K, L) = AK^\alpha L^{1-\alpha} \quad (6.8)$$

Where:

Y - total production,

K - capital outlay;

L - number of workers;

A - Total factor productivity.

$\alpha \in (0; 1)$ and $1 - \alpha \in (0; 1)$ – the elasticity of product Y with respect to capital input K and labor input L , respectively; at the same time, they represent the shares of these factors in the product on the basis of J.B. Clark's marginal theory of distribution.¹

The importance of the A parameter is related to the technological level of the economy, where a higher value of A indicates a higher ability to create product from given inputs. For $A > 0$, with unit inputs of capital and labor, $F(1, 1)$ equals A , which confirms that A determines productivity with baseline, unit inputs.

In the context of elasticity, if capital K (or labor L) increases by $C\%$, with fixed labor L (or fixed capital K and unchanged total factor productivity A), then output Y will increase by $C\alpha\%$ (or $C(1 - \alpha)\%$). This means that the parameters α and $1 - \alpha$ in the Cobb-Douglas function determine the proportional share of capital and labor inputs in total output.

The Cobb-Douglas production function is consistent with the assumptions of the neoclassical production function, including the assumption of homogeneity of degree one, which means that the function exhibits constant scale effects – a proportional increase in capital and labor inputs leads to a proportional increase in output.

The first formalized models of economic growth were developed by the Keynesian school and include, first and foremost, the model of Roy F. Harrod (1939), Evsey D. Domar (1946) and (after the Solow growth model was already established) the models of Michal Kalecki (1963, 1996) and Nicholas Kaldor (1963).

Keynesian economic growth models were developed under the strong influence of the Great Depression of the 1930s. Therefore, these models particularly emphasize mismatches between demand and supply-side determinants of economic growth. In turn, taking into account the fact that in Keynesian models of economic growth there is almost zero substitution of factor inputs (capital and labor) in the production process, it follows from these models that the market economy is threatened by a state of almost permanent imbalance. This threat lies in the underutilization of the economy's production capacity, which was relatively quickly accepted by Keynesian macroeconomics, which paid special attention to this problem (Barro and Sala-i-Martin, 1995).

In opposition (or alternative) to Keynesian economic growth models in 1956, Robert Solow proposed a neoclassical growth model using a Cobb-Douglas-type neoclassical production function. This model was later extended to, among other things, an economy with two capital stocks (Mankiw-Romer-Weil model, 1992) and any finite number N of capital stocks (Nonneman-Vanhoudt model, 1996). Solow's economic growth model is also based on the models of the new economic growth theory (the so-called endogenous growth theory), the most well-known examples of which are the growth models of Paul M. Romer (1986, 1990) and Robert E. Lucas (1988), after Dykas, Tokarski and Wisła (2023).

The 1956 Solow model often becomes the starting point for analyses of long-term economic growth (Snowdon and Vane, 2003; Tokarski, 2000, 2001, 2003, 2008, 2009). In its basic form, the model assumes that output in the economy is described by a neoclassical Cobb-Douglas production function (with technical progress in the Harrod sense) with the following formula: $t \in [0; +\infty]$

$$Y(t) = (K(t))^\alpha (A(t)L(t))^{1-\alpha} = (K(t))^\alpha (\tilde{L}(t))^{1-\alpha} \quad (6.9)$$

Where,

$Y(t)$ - The volume of the product stream produced in year t ;

$K(t)$ - physical capital stock in year t ;

$\tilde{L}(t) = A(t)L(t)$ - units of effective work in year t ;

$\alpha \in (0; 1)$ and $1 - \alpha \in (0; 1)$ – the elasticity of product Y with respect to capital input K and effective labor input \tilde{L} , respectively.

In the Solow model, the growth of physical capital is assumed to be the difference between investment in this capital and depreciation in the value of this capital. The stock of effective labor \tilde{L} grows according to the exogenous growth rate, which is the sum of the growth rate of the number of workers and the rate of technical progress in Harrod's sense (Filipowicz and Tokarski, 2016). It is defined as technical progress enhancing the efficiency of labor, which means that it is possible to achieve a fixed level of production with constant capital inputs, but with decreasing labor inputs over time, measured in natural units (Tokarski, 2009).

Critics of the Solow model point to the difficulty of meeting the above assumptions about equal access to technology (Mankiw, Romer and Weil, 1992). Among the weaknesses of the model is also mentioned the exogeneity of technical progress (the main factor of growth). This is because this assumption ignores the explanation of the main determinants of technical progress (Barro and Sala-i-Martin, 1995; Romer, 1996). In addition, in the 1960s there was a debate that attempted to develop the definition of capital. As a result, the concepts of human, social and intellectual capital emerged. None of these was used in the original version of Solow's model, which focuses only on physical capital (Roszkowska, 2013).

In response to the limitations of the Solow model, the Mankiw-Romer-Weil model (1992) was developed. The Solow model was extended to include a second capital stock (human capital [H] was added to physical capital) and an endogenous human capital stock growth equation (Tokarski, 2001). The model uses a modified Cobb-Douglas function, which at any time $t \in [0; +\infty)$ takes the form of the following equation:

$$Y(t) = \left(K(t) \right)^{\alpha_K} \left(H(t) \right)^{\alpha_H} \left(\tilde{L}(t) \right)^{1-\alpha_K-\alpha_H} \quad (6.10)$$

Where,

$\alpha_K, \alpha_H \in (0;1)$ and $1 - \alpha_K - \alpha_H \in (0;1)$ – the elasticity of product Y with respect to physical capital input K, human capital input H and effective labor input \tilde{L} , respectively.

The Mankiw-Romer-Weil (MRW) model makes the volume of output Y dependent on four factors of production: physical capital, labor stock, technical progress and human capital (Filipowicz and Tokarski, 2016). Analysis of the model leads to the conclusion that, regardless of the initial state, the economy is moving toward a point of stable long-term equilibrium. The position of the growth path along which the economy will move in equilibrium will be higher the higher the investment in human and physical capital and the lower their depreciation rates and growth rate of the labor force stock (Kawa, 2007).

The Mankiw-Romer-Weil model adopts an extended neoclassical production function that includes human capital alongside physical capital and labor, assuming constant returns to scale. The inclusion of human capital is significant because it recognizes the role of education and knowledge in economic growth, which traditional models such as the Solow model have not explicitly considered.

In the model, investment in the two types of capital is not substitutable in a fixed ratio; instead, the model suggests that there is a diminishing return on capital, requiring continuous investment to sustain growth. The interplay between physical and human capital provides the basis for endogenous growth, where the economy grows from within as a result of internal factors rather than external influences. This contrasts with exogenous growth models, where external factors such as

technological progress are seen as the main drivers of growth (Mankiw, Romer and Weil, 1992).

The model also generalizes Phelps' notion of the golden rule of accumulation from the Solow model for both types of capital. In the context of the MRW model, the golden rule is the level of capital investment that maximizes consumption per effective worker in a stationary state. Conditions for achieving the stationary state include balancing capital investment rates and their depreciation with the rate of labor force growth and technological progress.

Moreover, the MRW model assumes that higher savings rates and lower depreciation rates lead to higher levels of capital per worker and thus higher levels of output per worker in the stationary state. The model also takes into account the effect of population growth on the economy, arguing that lower population growth rates lead to higher levels of capital per worker and output per worker in the stationary state, due to less capital dilution.

In addition, there is a feedback loop between the accumulation of human capital and physical capital. An increase in investment in physical capital results in an acceleration of its accumulation. A faster increase in output per unit of effective labor will secondarily cause an acceleration in the accumulation of physical and human capital (Mankiw, Romer and Weil, 1992). An increase in the savings rate of human or physical capital will, in this model, result in an acceleration of the accumulation of both capital factors, an increase in output and a shift of the economy to a higher long-term growth path.

The Mankiw-Romer-Wail model was modified by Nonneman and Vanhoudt (1996), who included any finite number of capital inputs in their model. The increment of each resource is the difference between investment in the capital resource and its depreciation. The model describes the production process by a generalized $n+1$ -factor Cobb-Douglas production function with the following formula:

$$Y(t) = \left(\prod_{j=1}^n K_j(t)^{\alpha_j} \right) (\tilde{L}(t))^{1-\sum_j \alpha_j} \quad (6.11)$$

Where:

$$\alpha_j, \left(1 - \sum_j \alpha_j \right) \in (0,1) \quad j = 1, \dots, n$$

α_j – The elasticity of product with respect to the input of the j -th capital stock.

$1 - \sum_j \alpha_j$ - The flexibility of the product relative to the input of units of effective work.

In the Nonneman-Vanhoudt (NV) model, the amount of output per unit of effective labor increases as the rates of investment in capital resources increase and the

rates of depreciation of capital resources decrease. Productivity, understood as the value of output per unit of effective labor, is lower at high rates of growth in the number of workers (Nonneman and Vanhoudt 1996; Tokarski 2009, 2011).

In addition, the model depicts the complex interactions between capital resources, which are no longer treated as independent. This differentiation between capital resources enables more accurate modeling of real economic conditions, where different types of capital, such as physical, human or digital capital, can have different rates of depreciation and affect productivity differently. This approach allows for a more detailed analysis of the impact of digitization and innovation policies on long-term economic growth.

The NV model is an important extension of the Mankiw-Romer-Weil two-capital model, offering a deeper understanding of the mechanisms of economic growth by analyzing the impact of differentiated capital stocks on output. This approach is particularly useful in the context of today's digital economies, where the variation in forms of capital is significant and where economic policy must take these differences into account to effectively stimulate growth.

In the case of the Schumpeterian theory of creative destruction, innovations that generate technical progress are key. The pioneers of the Schumpeterian theory of economic growth are Phillipe Aghion and Peter Howitt (1992), who mathematically described economic growth based on innovations paid for and generated by companies led by visions of above-average profit and market monopolization. Subsequent innovations displace older solutions and technologies by means of creative destruction described in Chapter 2. Creative destruction cleanses the market of old technologies and inefficient enterprises by which it gives birth to technical progress for the entire economy. Key to the dynamics of progress are the productivity of the capital accumulation sphere and access to skilled workers (human capital) (Aghion and Howitt, 1992, 2009, 2013; Acemoglu, 2009; Barro and Sala-i-Martin, 2004; Grodzicki, 2016).

The development of the digital economy is triggered by radical technological changes that are transforming the production process of the entire economy. Its development consists of both investment in digital infrastructure and the development of digital skills among the population. This means that a model describing the impact of digitization on economic growth must include, in addition to traditional physical capital and the labor force stock, human capital and the stock of "digital" capital. The latter may consist of one or more variables describing the level of development of the digital economy, which in this study is reduced to the category of digital saturation. By this term what is meant is the degree to which the ICT sector influences the traditional economy and how heavily the traditional economy is dependent on ICT. Digital saturation indicates how much a country's economy has been transformed by digital transformation.

The indicated line of research into the complementarity of human capital and the digital economy (hypothesis three), secular stagnation and the productivity paradox addressed in Chapter 2 point to the production function used in the Nonneman-Vanhoudt's n-factor model, in which human capital and the degree of digital saturation are placed in addition to traditional (physical) capital.

6.3 Taxonomic index of digital saturation

Taxonomic methods make it possible to classify countries and regions by typifying them with metric measures. The measures transform *the n-dimensional* space of variables describing the level of the phenomenon under study into a one-dimensional real space. The need for taxonomic measures is mainly due to the fact that in n -dimensional spaces ($n \geq 2$) there is no good order (understood as an unambiguous order that meets the conditions of crossover relations, antisymmetry and transitivity). This makes it difficult to compare arbitrary feature vectors (Dykas, Koscielniak and Tokarski, 2013).

Synthetic variables (first) allow for the ordering and comparison of countries (regions) and, second, these variables allow for the classification of countries (regions) into groups with a similar degree of development of a given phenomenon. This study relied on the 11 (cf. Biernacki, Luśtyk and Wisła, 2023) selected variables described in Chapter 5. The selection of variables was based on the adoption of a macroeconomic perspective and the availability of sufficiently long-time series for as many economies as possible, so that the phenomenon of the digital economy could be described as accurately as possible. These are respectively:

- Share of ICT specialists in total workforce;
- ICT sector's contribution to GDP;
- ICT imports;
- ICT exports;
- Share of companies employing ICT specialists;
- ICT companies' R&D spending;
- E-commerce sales value;
- Participation of Internet users in dealing with public authorities;
- Share of people working remotely;
- Share of people using e-commerce;
- Share of population using online banking.

The economic and social variables described in Chapter 5 were used to create a taxonomic index of digital saturation. The data comes from Eurostat and cover the range from 2012 to 2019. There are 11 country-level variables for 23 countries (Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Estonia, Greece, Spain, France, Croatia, Italy, Latvia, Lithuania, Hungary, Malta, the Netherlands, Austria, Poland, Romania, Slovenia, Slovakia, Finland and the United Kingdom) hereafter referred to as the EU28 group (due to its nature of describing the level of the entire European Union). Sweden was excluded from the data because of the lack of data on the share of ICT professionals in the total workforce. In addition, Portugal, Luxembourg, Ireland and Cyprus were not included in the study because of the lack of the necessary data. Norway was also excluded in order to focus only on European Union countries. All data were standardized; in addition, for the value of import and export streams, the data were first adjusted for inflation (2012=100).

The group of 23 countries was divided into 4 subgroups (quartile groups) using the criterion of GDP per capita at PPP (data from Eurostat). The GDP1 group contains countries with the highest value of GDP per capita, while GDP4 are countries with the lowest value of GDP per capita. For the selected groups, four separate taxonomic indicators of digital saturation were constructed for, respectively:

- GDP1 – The Netherlands, Denmark, Austria, Germany, Belgium, Finland;
- GDP2 – Malta, France, Italy, the United Kingdom, Slovenia, Czech Republic;
- GDP3 – Lithuania, Estonia, Spain, Poland, Hungary, Romania;
- GDP4 – Latvia, Croatia, Greece, Slovakia, Bulgaria.

Each of the 11 variables acts as stimulants, with their high values being favorable in the context of analyzing digital saturation in the traditional economy. As previously mentioned, the research process involved normalizing all stimulants. This was realized by dividing the value of each by its maximum value, thus eliminating the units of measurement:

$$z_{ijt} = \frac{x_{ijt}}{\max_{i,t}(x_t)}, \quad (i = 1, \dots, 23, j = 1, \dots, 11, t = 2012, \dots, 2019) \quad (6.12)$$

Where z_{ijt} denotes the standardized j -th stimulant for the i -th country in year t . The values of z_{ijt} are both not greater than 1 and not less than 0, making it possible to compare any values of the standardized stimulants.

The analysis adopted a taxonomic method based on the maximum value of the sum of Pearson’s linear correlation coefficients between the taxonomic index (T_i^t) and the normalized stimulants (Dykas, Koscielniak and Tokarski, 2013).

Let S be a matrix of variables representing stimulants, where s_{ij} is equal to the value of *the j -th stimulant* in the i -th country. Z represents the matrix S after normalization, where the normalization process is carried out by applying the following transformation:

$$Z_{ij} = \frac{S_j}{\max(S_j)} \quad (6.13)$$

when *the j -th column* of the matrix S is the stimulant and:

$$Z_{ij} = 1 - \frac{S_j}{\max(S_j)} \quad (6.14)$$

when *the j -th column* of the matrix S is a destimulant.

According to the presented description of the meaning of the synthetic variables used in this study to describe digital saturation, all are stimulants. The taxonomic index T_i^j for the development of *the* i -th country in year t is defined as a convex linear combination of characteristics after normalization:

$$T_i^j = \omega_1 Z_{i,1} + \omega_2 Z_{i,2} + \omega_3 Z_{i,3} + \dots + \omega_{11} Z_{i,11} \quad (6.15)$$

Where $\omega = (\omega_1, \omega_2, \omega_3, \dots, \omega_{11})$ represents the set of weights that maximizes the following correlation function:

$$F(\omega) = \sum_{j=1}^{11} \text{cor}(Z_{i,j}, Z \cdot \omega) \quad (6.16)$$

The taxonomic index T_i^j (for $i=1, 2, \dots, 23$), where i denotes the next country surveyed in the EU28 group, takes values in the range $<0,1>$. The value of this indicator can be interpreted to mean that the closer it is to unity, the higher the level of digital saturation found in a country.

On the contrary, the calculated vector of weights ω_i (for $i=1, 2, \dots, 11$), where i denotes the next synthetic variable used in the calculation. Determination of the vector of weights ω is a rather tedious process by which in practice appropriate optimization algorithms are used for this purpose. The coordinates of the weights were determined using the Python programming language and the Sequential Least Squares Programming (SLQP) method available in the *scipy* optimize module. The method allows immediate determination of weights for 11 variables and is recommended by minimizing the error function while satisfying the requirement that the weights are in the interval $(0,1)$ and their sum is 1. The interpretation of the value of the weights ω is as follows: the larger the value of the weight, the greater the influence of the stimulant on the value of the taxonomic index.

Finally, the following weights were determined for the standardized variables for the EU28 group (reaching a correlation sum value of 6,884):

- Share of ICT specialists in the total workforce – 0,118;
- ICT's share of GDP – 0,130;
- ICT imports – 0,087;
- ICT exports – 0,067;
- Share of companies employing ICT specialists – 0,115;
- ICT sector R&D expenditures – 0,089;
- E-commerce sales value – 0,089;
- Share of people using the Internet to interact with public authorities – 0,078;
- The share of people working remotely – 0,072;
- Share of people using e-commerce – 0,085;
- Share of population using online banking – 0,07.

A comparative analysis of the results obtained allows us to conclude that there are small deviations with a fairly constant gradation of the significance of the variables.

As a result, a matrix of taxonomic index values for the EU28 group of countries in 2012–2019 was created (see Table 6.1.)

Analysis of changes in the values of the digital saturation index in the EU28 group leads to the following statements. The highest values of the digital saturation index in 2012 were recorded in: the United Kingdom, Finland, Denmark, Netherlands and Malta. In 2019, the highest values were in: Finland, the United Kingdom, the Netherlands, Denmark and Malta. The lowest values in 2012 were in: Romania, Bulgaria, Italy, Greece and Croatia. And in 2019, the lowest values were in Romania, Greece, Italy, Bulgaria and Lithuania.

The spread of extreme scores between 2012 and 2019 fell from 0,46 to 0,42 and the average level of the index increased between 2012 and 2019 from 0,42 to 0,49. The above-average score in 2012 was achieved by 12 countries (including 4 from the New Union – Malta, Estonia, the Czech Republic and Hungary). In 2019, an above-average score was recorded in 11 countries (including the same 4 New Union countries). The standard deviation of the results fell from 0.13 in 2012 to 0.12 in 2019.

Table 6.1 Values of the taxonomic index of digital saturation for the EU28 group

Country	2012	2013	2014	2015	2016	2017	2018	2019
Austria	0,453	0,452	0,449	0,463	0,471	0,471	0,471	0,487
Belgium	0,474	0,475	0,492	0,514	0,521	0,541	0,549	0,569
Bulgaria	0,220	0,240	0,268	0,276	0,317	0,330	0,352	0,370
Croatia	0,309	0,320	0,330	0,355	0,345	0,347	0,381	0,397
Czech Republic	0,428	0,423	0,440	0,437	0,455	0,488	0,497	0,527
Denmark	0,609	0,609	0,605	0,596	0,602	0,594	0,610	0,626
Estonia	0,455	0,457	0,494	0,538	0,548	0,560	0,591	0,609
Finland	0,611	0,613	0,629	0,637	0,636	0,657	0,657	0,676
France	0,518	0,491	0,535	0,557	0,583	0,587	0,589	0,572
Germany	0,496	0,492	0,510	0,530	0,524	0,540	0,574	0,568
Greece	0,301	0,283	0,286	0,303	0,331	0,288	0,308	0,312
Hungary	0,460	0,452	0,469	0,444	0,442	0,464	0,481	0,497
Italy	0,292	0,298	0,301	0,323	0,325	0,333	0,339	0,346
Latvia	0,347	0,356	0,384	0,403	0,426	0,430	0,443	0,486
Lithuania	0,322	0,313	0,320	0,330	0,331	0,377	0,378	0,393
Malta	0,535	0,518	0,529	0,545	0,561	0,590	0,596	0,614
Netherlands	0,604	0,626	0,643	0,637	0,617	0,642	0,665	0,653
Poland	0,309	0,296	0,301	0,325	0,355	0,355	0,374	0,432
Romania	0,188	0,178	0,200	0,221	0,232	0,223	0,240	0,249
Slovakia	0,412	0,398	0,412	0,430	0,429	0,453	0,447	0,468
Slovenia	0,364	0,372	0,382	0,386	0,387	0,404	0,417	0,423
Spain	0,375	0,379	0,401	0,401	0,417	0,419	0,423	0,431
United Kingdom	0,649	0,643	0,642	0,651	0,647	0,623	0,649	0,674

Source: Own study.

The largest increase in the value of the index between 2012 and 2019 was recorded in Bulgaria (by 68,1%), Latvia (by 39,9%), Poland (by 39,9%), Estonia (by 338%) and Romania (by 32,5%). The lowest increases were recorded in Austria (by 7,5%), the United Kingdom (by 3,8%), Greece (by 3,8%) and Denmark (by 2,8%). No country in the study period saw a decrease in the value of the index from 2012 to 2019.

Thus, a certain constancy of results is apparent when it comes to the gradation of countries. Despite the impressive increases in the index values of the New Union countries, the number of above-average results has not increased. On this basis, it can be cautiously presumed that in the following years the level of digital saturation will increase and the differences between countries will continue to blur. However, any shifts of countries within the ranking of digital economy development will be rare.

Figure 6.1 shows quintile groups of values of the taxonomic index of digital saturation in 2012 and 2019 in the EU28 group. The first quintile group, marked with the darkest color, contains countries with the highest value of the studied characteristic. The last group is marked with the lightest color and contains countries with the lowest value of the trait.

From an analysis of the contents of Table 6.1 and Figure 6.1, the following conclusions can be drawn:

- In the first quintile group in 2012 (taking values from 0,528 to 0,649) were: Denmark, Finland, Malta, the Netherlands and the United Kingdom. In 2019, the composition in the first quintile group (with values from 0,612 to 0,676) was identical;
- The second quintile group in 2012 (taking values from 0,426 to 0,528) included: Belgium, France, Germany and Hungary. In 2019, the second quintile



Figure 6.1 Value of the taxonomic index of digital saturation for the EU28 group in 2012 and 2019.

Source: Own study.

group (with values ranging from 0,535 to 0,612) included: Belgium, France, Germany and Estonia;

- In the third quintile group in 2012 (taking values from 0,373 to 0,426) were: Austria, the Czech Republic, Estonia, Slovakia and Spain. In 2019, the third quintile group (with values from 0,461 to 0,535) included: Hungary, Austria, the Czech Republic, Slovakia and Latvia;
- In the fourth quintile group in 2012 (taking values from 0,309 to 0,373) were: Latvia, Lithuania, Poland and Slovenia. In 2019, the fourth quintile group (with values ranging from 0,395 to 0,461) included: Spain, Poland, Slovenia and Croatia;
- The last quintile group in 2012 (taking values from 0,188 to 0,309) included: Bulgaria, Croatia, Greece, Italy and Romania. In 2019, the last quintile group (taking values from 0,249 to 0,395) included: Lithuania, Bulgaria, Greece, Italy and Romania.

In summary, an analysis of the contents of Table 6.1 and Figure 6.2 leads to the following simple generalizations:

- The composition of group one did not change between 2012 and 2019;
- Estonia advanced from group three to group two, likewise Latvia from group four to group three and Croatia from the last group to group four;
- Hungary dropped from group two to group three;
- Spain dropped from group three to group four;
- Lithuania dropped from the fourth to the last group.

The growing role of the eastern EU countries in building the digital economy is therefore evident. It should further strengthen over the years, thanks to the progressive spread and maturation of the digital economy. The role of the Baltic countries, the Czech Republic, Hungary and Malta – where exceptionally high shares of ICT specialists in employment, shares of companies employing ICT specialists, R&D spending and the relevance of online sales were observed – is particularly important here. This may be due to long-standing programs aimed at developing digital infrastructure and training programs for digital specialists. They are the ones that are coming in place of countries such as Italy, Spain and Greece achieving results that position them economically among the Old Union. And thanks to the high growth rate of Eastern Europe's digitization, more countries in the region will achieve above-average results. The shift in the axis of development of "digital Europe" as measured by the level of digital saturation is the main finding from the analysis of the taxonomic index of digital saturation.

For the GDP1, which includes Austria, Belgium, Denmark, Finland, Germany and the Netherlands, the following weights were set for the standardized variables:

- Share of ICT specialists in the total workforce – 0,111;
- ICT's share of GDP – 0,14;
- ICT imports – 0,05;

- ICT exports – 0,045;
- Share of companies employing ICT specialists – 0,147;
- ICT sector R&D expenditures – 0,058;
- E-commerce sales value – 0,087;
- Share of people using the Internet to interact with public authorities –0,12;
- The share of people working remotely – 0,064;
- Share of people using e-commerce – 0,096;
- Share of population using online banking – 0,082.

The highest weighting was given to the share of companies employing ICT specialists (0,147), the share of ICT in GDP (0,14) and the share of people using the Internet to interact with public authorities (0,12). ICT exports were high (0,045), ICT imports (0,05) gained the least importance and ICT sector spending on R&D was (0,058).

Table 6.2 contains the values of the taxonomic index of digital saturation for countries of the GDP group1 in 2012–2019.

Analysis of changes in the value of the digital saturation index in the GDP1 group leads to the following statements. First, the highest values of the digital saturation index in 2012 are observed in Denmark, Finland and the Netherlands, respectively. In 2019, the highest values are recorded, respectively: Finland, the Netherlands and Denmark. The lowest values in 2012 were observed in Austria, Belgium and Germany. In 2019, the lowest values were observed in Austria, Germany and Belgium, respectively.

The highest average score in the period under review was achieved by the Finnish economy (0,768) and the Dutch economy (0,759). The lowest average score was recorded in Austria (0,567) and Belgium (0,628). The average score for the entire GDP1 group increased from 0,655 in 2012 to 0,719 in 2019. The standard deviation dropped minimally from 0,0876 in 2012 to 0,0817 in 2019, which can be interpreted as a fading dispersion between countries. At the same time, the difference between the highest and lowest reading increased over the period under review, from 0,19 in 2012 to 0,22 in 2019.

Figure 6.2 shows the groups of changes in the value of the taxonomic index of digital saturation between 2012 and 2019 in the GDP1 group.

Table 6.2 Values of the taxonomic index of digital saturation for the GDP1 group

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Austria	0,554	0,553	0,547	0,564	0,575	0,576	0,573	0,591
Belgium	0,581	0,581	0,599	0,622	0,629	0,655	0,664	0,690
Denmark	0,743	0,747	0,744	0,732	0,740	0,731	0,754	0,772
Finland	0,734	0,740	0,756	0,761	0,764	0,794	0,787	0,808
Germany	0,592	0,593	0,614	0,635	0,630	0,643	0,678	0,674
Netherlands	0,724	0,749	0,762	0,760	0,742	0,770	0,790	0,778

Source: Own study.

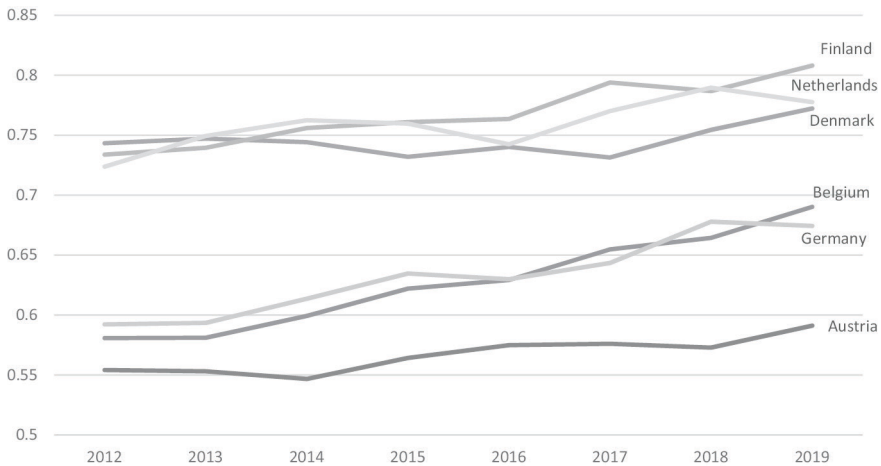


Figure 6.2 Digital saturation taxonomy index for GDP1 group from 2012 to 2019.

Source: Own study.

Figure 6.2 shows the distinguished groups:

- Finland, the Netherlands and Denmark;
- Germany and Belgium;
- Austria.

A persistent gap between the three groups is evident throughout the study period. Despite the positive trend in dynamics between 2012 and 2019, the gap between Austria and Germany and Belgium has widened, with Belgium achieving the highest growth rate in the value of the index, based on the high performance of three variables (share of ICT specialists in total employment, share of companies employing ICT specialists, share of online sales in total company sales). Austria's low position is due to the fact that in addition to the four variables (ICT exports and imports, e-government, prevalence of remote work) it performs average or below average. Only in the case of the share of people working remotely did it boast the third best score.

For the GDP2 group, which includes the Czech Republic, France, Italy, Malta, Slovenia and the United Kingdom, the following weights were set for the standardized variables:

- Share of ICT specialists in the total workforce – 0,123;
- ICT's share of GDP – 0,103;
- ICT imports – 0,06;
- ICT exports – 0,051;
- Share of companies employing ICT specialists – 0,124;

- ICT sector R&D expenditures – 0,071;
- E-commerce sales value – 0,085;
- Share of people using the Internet to interact with public authorities –0,087;
- The share of people working remotely – 0,103;
- Share of people using e-commerce – 0,093;
- Share of population using online banking – 0,1.

The highest weights were given to the share of companies employing ICT specialists (0,124), the share of ICT specialists in the total workforce (0,123) and the share of people working remotely (0,103). In contrast, the lowest weights in the GDP2 group were given to ICT exports (0,051), ICT imports (0,06) and ICT R&D expenditures (0,071), which is a twin to the GDP1 group.

Table 6.3 contains the values of the taxonomic index of digital saturation for the countries of the GDP2 group in 2012–2019.

It can be inferred from Table 6.3 that in 2012 the highest values were observed for the United Kingdom, French and Maltese economies, respectively. In 2019, the highest readings were in the United Kingdom, Malta and France, respectively. In both 2012 and 2019, the lowest values were in Italy, Slovenia and the Czech Republic

Between 2012 and 2019, the average value of the index in the GDP2 group increased from 0,511 to 0,590. The standard deviation minimally decreased from 0,129 in 2012 to 0,128 in 2019. At the same time, the difference between the extremes fell from 0,360 (in 2012) to 0,350 (in 2019).

Figure 6.3 shows the groups of changes in the value of the taxonomic index of digital saturation between 2012 and 2019 in the GDP2 group.

An analysis of Figure 6.3 shows that in terms of digital saturation, the Italian economy is performing significantly lower relative to the rest of the GDP2 group. The Czech Republic and Slovenia started from a similar level, but the Czech economy in 2019 neared the performance of Malta and France. The level of digital saturation of the latter economies was similar and relatively stable over the period under review. The invariable leader in the GDP2 group was the United Kingdom maintaining its lead over the rest of the countries. The Italian case is most likely

Table 6.3 Values of the taxonomic index of digital saturation for the GDP2 group

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Czech Republic	0,480	0,475	0,494	0,489	0,510	0,553	0,565	0,601
France	0,597	0,557	0,593	0,613	0,635	0,644	0,650	0,645
Italy	0,316	0,323	0,330	0,356	0,359	0,368	0,377	0,385
Malta	0,570	0,556	0,572	0,590	0,611	0,638	0,652	0,678
Slovenia	0,429	0,442	0,454	0,457	0,457	0,475	0,492	0,498
United Kingdom	0,676	0,669	0,674	0,680	0,687	0,668	0,702	0,735

Source: Own study.

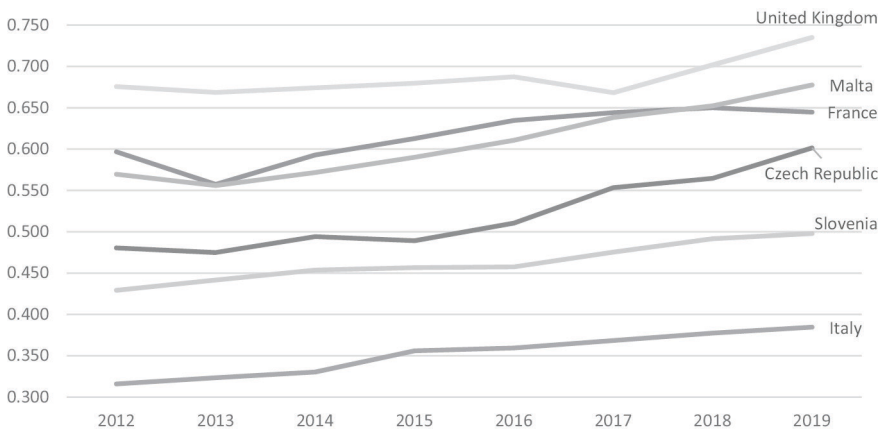


Figure 6.3 Digital saturation taxonomy index for the GDP2 group from 2012 to 2019.

Source: Own study.

due to the achievement of very low values in all variables (except exports and ICT imports). In the case of the share of firms employing ICT professionals, among others, Italy had one of the lowest scores in the EU, while the share of ICT R&D spending of total R&D expenditures has declined through 2019.

For the GDP3 group, which includes Estonia, Hungary, Lithuania, Poland, Romania and Spain, the following weights were set for the standardized variables:

- Share of ICT specialists in the total workforce – 0,129;
- ICT's share of GDP – 0,11;
- ICT imports – 0,067;
- ICT exports – 0,064;
- Share of companies employing ICT specialists – 0,097;
- ICT sector R&D expenditures – 0,096;
- E-commerce sales value – 0,109;
- Share of people using the Internet to interact with public authorities – 0,09;
- The share of people working remotely – 0,081;
- Share of people using e-commerce – 0,085;
- Share of population using online banking – 0,072.

The highest weights were assigned to the share of ICT professionals in the total workforce (0,129), the share of ICT in GDP (0,11) and the value of e-commerce sales (0,109). The lowest weights were assigned to ICT exports (0,064), ICT imports (0,067) and the share of the population using online banking (0,072). In contrast to the GDP1 and GDP2 groups, e-commerce sales are more strongly emphasized, while online banking gains a low weight.

Table 6.4 Values of the taxonomic index of digital saturation for the GDP3 group

<i>Country</i>	<i>2012</i>	<i>2013</i>	<i>2014</i>	<i>2015</i>	<i>2016</i>	<i>2017</i>	<i>2018</i>	<i>2019</i>
Estonia	0,566	0,569	0,618	0,670	0,686	0,700	0,742	0,759
Hungary	0,570	0,563	0,588	0,562	0,556	0,588	0,605	0,622
Lithuania	0,403	0,387	0,397	0,411	0,413	0,467	0,471	0,492
Poland	0,440	0,436	0,444	0,479	0,508	0,497	0,519	0,585
Romania	0,235	0,223	0,249	0,278	0,291	0,282	0,303	0,312
Spain	0,557	0,548	0,584	0,587	0,613	0,620	0,631	0,638

Source: Own study.

Table 6.4 contains the values of the taxonomic index of digital saturation for the countries of the GDP3 group in 2012–2019.

It can be deduced from Table 6.4 that in 2012, the highest values of the digital saturation index were in Hungary, Estonia and Spain, respectively. In 2019, the highest readings were in Estonia, Spain and Hungary, respectively. The lowest values in both in 2012 and 2019 were obtained by: Romania, Lithuania and Poland.

Between 2012 and 2019, the average value of the index in the GDP3 group increased from 0,462 to 0,568. The difference between the extremes increased from 0,335 (in 2012) to 0,447 (in 2019). The standard deviation increased from 0,132 in 2012 to 0,152 in 2019, which can be interpreted as the progressive convergence of the GDP3 group countries.

Figure 6.4 shows the changes in the value of the taxonomic index of digital saturation between 2012 and 2019 in the GDP3 group.

An analysis of Figure 6.4 shows that in terms of digital saturation, Romania has been lagging behind the rest of the group throughout the period, obtaining by far the lowest results. At the same time, in 2012, the results of Estonia, Spain and Hungary were strongly similar, while in 2019 Estonia distanced the other two countries by being the leader of the GDP3 group. In the middle of the group were Poland and Lithuania. Poland, however, achieved the highest growth rate approaching Hungary and Spain. The Romanian case is due to achieving some of the lowest values for most variables in the years analyzed. Estonia, on the contrary, achieved its strong position thanks to its high value-added ICT sector, R&D expenditures, e-government, remote working or the popularity of online banking.

For the GDP4 group, which includes Bulgaria, Croatia, Greece, Latvia and Slovakia, the following weights were set for the standardized variables:

- Share of ICT specialists in the total workforce – 0,104;
- ICT's share of GDP – 0,107;
- ICT imports – 0,091;
- ICT exports – 0,069;
- Share of companies employing ICT specialists – 0,161;
- ICT sector R&D expenditures – 0,096;

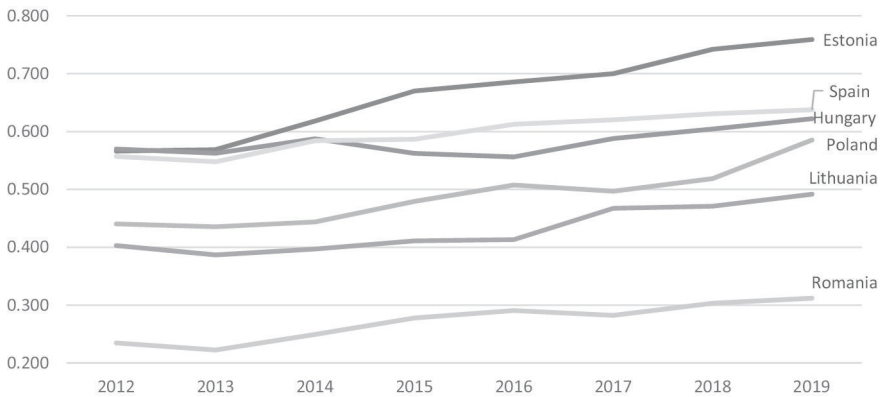


Figure 6.4 Digital saturation taxonomy index for the GDP3 group from 2012 to 2019.

Source: Own study.

- E-commerce sales value – 0,069;
- Share of people using the Internet to interact with public authorities – 0,085;
- The share of people working remotely – 0,064;
- Share of people using e-commerce – 0,089;
- Share of population using online banking – 0,065.

The highest weights were given to the share of companies employing ICT specialists (0,161), the share of ICT in GDP (0,107) and the share of ICT specialists in the total workforce (0,104). The lowest weights were given to the share of people working remotely (0,064), the share of the population using online banking (0,065), ICT exports (0,069) and the value of e-commerce sales (0,069). Of interest is the weight of the last variable, which reached the third highest weight for the GDP3 group.

Table 6.5 contains the values of the taxonomic index of digital saturation for the countries of the GDP4 group in 2012–2019.

From Table 6.5 it can be deduced that in 2012, the highest values in the GDP4 group were in Slovakia, Greece and Latvia. In 2019, the highest readings were in Slovakia, Latvia and Croatia. In 2012, the lowest readings were in Bulgaria, Croatia and Latvia. And in 2019, the lowest values were in Greece, Bulgaria and Croatia.

Between 2012 and 2019, the average value of the digital saturation index for the GDP4 group increased from 0,487 to 0,587. The standard deviation decreased from 0,134 in 2012 to 0,1 in 2019. At the same time, the difference between the extremes fell from 0,354 (in 2012) to 0,221 (in 2019).

Figure 6.5 shows the groups of changes in the value of the taxonomic index of digital saturation between 2012 and 2019 in the GDP4 group.

An analysis of Figure 6.5 shows that the spread of values of the digital saturation index in the GDP4 group has been decreasing from 2012 to 2019. The invariable

Table 6.5 Values of the taxonomic index of digital saturation for the GDP4 group

Country	2012	2013	2014	2015	2016	2017	2018	2019
Bulgaria	0,294	0,320	0,360	0,380	0,441	0,459	0,473	0,501
Croatia	0,445	0,458	0,477	0,518	0,497	0,500	0,546	0,559
Greece	0,572	0,490	0,493	0,506	0,569	0,488	0,495	0,492
Latvia	0,478	0,486	0,528	0,545	0,580	0,577	0,607	0,670
Slovakia	0,647	0,625	0,663	0,699	0,678	0,697	0,693	0,713

Source: Own study.

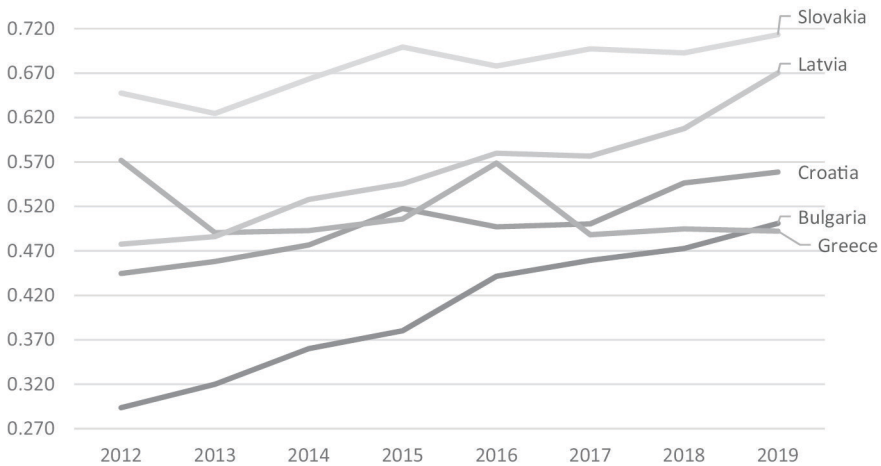


Figure 6.5 Digital saturation taxonomy index for the GDP4 group from 2012 to 2019.

Source: Own study.

leader throughout the analyzed period remains Slovakia. The largest growth is recorded in Bulgaria, whose index values increased by 71% from 2012 to 2019. At the same time, Greece records a 14% decrease in the value of the index between 2012 and 2019 – a phenomenon unique across all four groups studied. This puts Greece ahead of as many as three countries – Latvia, Croatia and Bulgaria, respectively. Bulgaria's result is mainly based on the high growth of the ICT sector's value added. Greece, on the contrary, has been moving over the years to the group of countries with the lowest values of the analyzed variables. In the case of ICT sector value added, among others, Greece's score was the lowest of all the 23 countries analyzed.

The results of the author's resulting digital saturation index were contrasted with the various indices discussed in Chapter 4. Indexes measuring the level of economic and social development (HDI, EIS, GII) scored much higher for Austria, Spain and Slovenia. Malta and Estonia scored lower on the digital saturation index.

Indexes measuring the level of technological development also valued Austria higher than the author’s index, as did Germany and Spain. The economies of Croatia, the Czech Republic, Hungary Bulgaria and Malta, on the contrary, performed worse.

The regulatory and administrative perspective analyzed through the prism of the EGDI and DTRI indices shows better results than the author’s index in the case of Latvia, the Czech Republic, Slovenia, Croatia, Bulgaria. While the Finnish, Danish, French, German, and Belgian economies show worse results.

The results of the DESI and HCI indices, which measure the level of development of human capital and social capital, also differ significantly from the taxonomy’s digital saturation index. Lithuania, Spain, Slovenia and Austria outperform the author’s index, in contrast to the performance of Malta, France, Hungary or Germany.

This means that the gradation using the author’s digital saturation index offers a unique view of the level of development of the digital economy. At the same time, the authors recognize valuable issues such as the fact that Western European countries are much stronger on issues of traditional economic and technological wealth, which is confirmed by the first two categories of the indexes (economic-social and technological), while on issues of regulation, legislation and administration the performance of the New Union countries is better than the digital saturation would suggest, which may indicate the potential for further promotion of digital innovation in these countries.

A Sankey visualization was used to verify the second hypothesis treating the complementarity of human capital and digital saturation. Figure 6.6 on the left

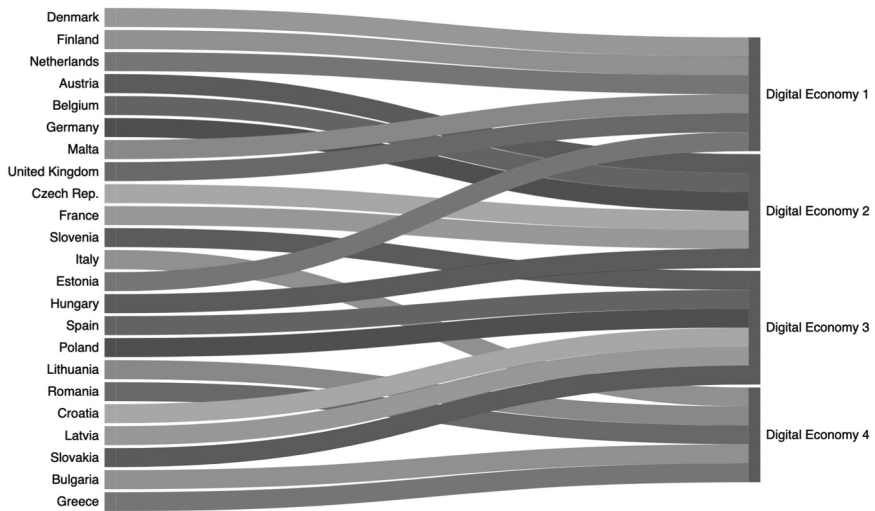


Figure 6.6 Differences between traditional gradation and according to digital saturation.

Source: Own study.

shows the surveyed European countries ranked by GDP per capita (for 2019). As one moves to the right, the graph indicates which quartile group by digital saturation (level of development of the digital economy) a country qualifies for. The digital gradation uses the values of the taxonomic index of digital saturation.

The leading role of Denmark, Finland and the Netherlands, which both in the traditional gradation (by GDP criterion) and by digital saturation, are at the forefront of Europe. Similarly stable results in both gradations are recorded by the Czech Republic, France, Spain, Poland, Bulgaria and Romania.

Higher rankings in terms of digital saturation than the traditional wealth distribution would suggest were achieved by Malta and the United Kingdom (from GDP2 to Digital Economy 1), Hungary (from GDP3 to Digital Economy 2) and Croatia, Latvia and Slovakia (from GDP4 to Digital Economy 3). Against this backdrop, the Italian and Estonian results stand out. Italy's economy, despite being in the second group by GDP, qualifies for the last group in terms of digital saturation. Estonia, on the other hand, is an example of a country with a much more strongly developed digital economy than its GDP per capita would suggest. The Estonian economy is in Digital Economy Group 1, following the traditional division in the GDP group.

So, apart from these individual examples, usually the results for traditional and digital division are the same or differ by one group.

Figure 6.7 has been expanded to include a gradation by the level of human capital in a given economy (left side).² The middle gradation is the traditional breakdown by GDP per capita, while on the right is a gradation by digital saturation.

An analysis of Figure 6.7 reveals a correlation that high levels of traditional wealth co-occur with high levels of human capital and strong digital saturation

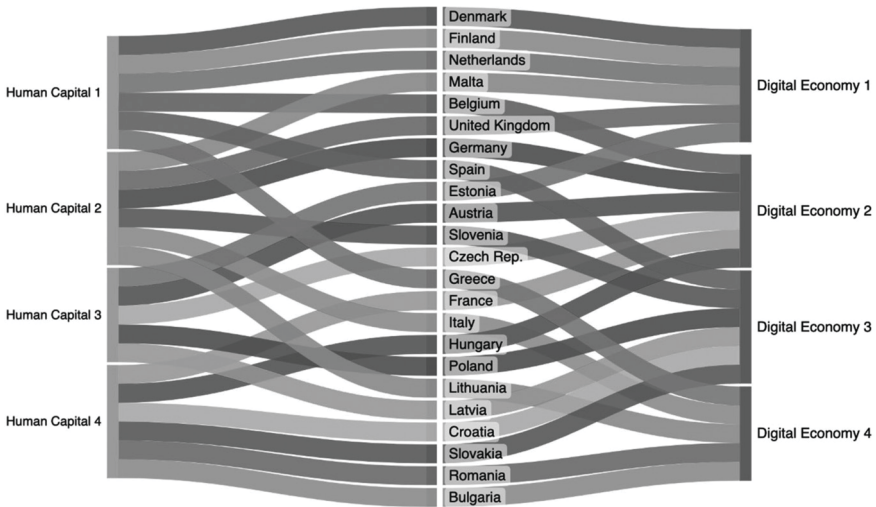


Figure 6.7 Differences in the gradation of European countries by GDP per capita, human capital and digital saturation.

Source: Own study.

(e.g., Denmark, the Netherlands and Finland). The “ribbon” of the Polish and Bulgarian economies looks similar.

Interesting examples are Germany, Austria and, to a lesser extent, Romania. These countries score higher in the traditional ranking (by GDP) than in the areas of human capital and digital economy. A horseshoe-shaped graph is forming, which may indicate the challenge in the coming years of economic development being held back by an insufficiently innovative economy.

The opposite situation is also observed (the case of Latvia), in which the country achieves a relatively low GDP compared to a relatively high level of human capital and digital economy (the inverted horseshoe).

The vast majority of countries in the two rankings perform similarly, and the third variable is relatively over- or underestimated. In the case of the Czech Republic and France, the level of human capital is lower than the digital economy and GDP which are similar. The situation is similar in the United Kingdom, Malta and Croatia, where the country is relative to its traditional wealth underinvested in human capital and highly saturated with digital. The Hungarian and Estonian economies stand out the most, being “dragged down” by the digital economy and “hampered” by human capital.

At the other extreme are countries such as Lithuania, Spain and especially Italy and Greece. These are countries that have disproportionately low values of digital saturation relative to their levels of traditional wealth and high levels of human capital. To a lesser extent, underinvestment in the digital economy with developed human capital is evident in Slovenia and Belgium.

The examples of Spain, Italy and Greece are so puzzling that they had to be contrasted with other factors that may artificially inflate the human capital score. In the case of the share of people with tertiary education in technical and mathematical sciences (STEM; Eurostat [2023]; Database: sc00025) in total employment, the three economies analyzed perform below the EU average, with Italy having the third lowest score in the EU28 group. The same goes for the number of STEM PhDs defended per 1,000 population, where the analyzed three economies perform below average (Eurostat [n.d.]; Database: educ_uoe_grad07). For overall tertiary education, 46,5% of Spaniards, 42,4% of Greeks and 27,7% of Italians aged 25–34 have it, against an EU average of 39,4% (Eurostat [2023]; Database: sdg_04_20). In the case of the number of universities, the advantage of the southern countries is not apparent either. Spain has 276 universities, Greece 66 and Italy 289.

In comparison, Poland has 408, France has 625 and Germany has 461 (webometrics, 2024). Thus, in these countries, the expected length of education does not translate into the quality of human capital, which may be related to the lack of graduation, frequent changes of majors or treating education as an excuse to continually postpone taking up gainful employment.

In the context of the second hypothesis treating the complementarity of human capital and the digital economy as a determinant of economic growth, the above analysis leads to the following conclusions. Among the leaders, high GDP is accompanied by high digital saturation and high levels of human capital. Confronting the conclusions from Chapter 5 with the analysis of the leaders in digital development,

one can cautiously assume the superiority of a highly developed digital economy over human capital (the case of Estonia, the United Kingdom and Hungary). At the same time, countries that are struggling to develop digital economy (Spain, Greece and Italy), despite high levels of human capital, are not able to develop digitally, which could be a strong developmental brake in the coming decades. When juxtaposed with the debt problem and high unemployment, especially among young people, this could be a recipe for decades of economic stagnation.

6.4 Impact of digital economy development on economic growth

Analysis of the economic growth models of Mankiw-Romer-Weil (1992) and Nonneman-Vanhoudt (1996) indicate that human capital is one of the factors of production (Roszkowska, 2013). In the era of digitization and Industry 4.0, in order for the model to better represent reality, it is suggested to replace the labor force resource with human capital (İzgiKaradag and Beceren, 2020). In the reality of the digital economy, more important than the sheer number of “working hands” is their quality, expressed in knowledge, skills and know-how (Olender-Skorek, 2017). In addition, one of the manifestations of the digital transformation is the robotization of jobs.

Digitalization is changing the perceptions of traditional paradigms in economics to such an extent that it is necessary to add more factors of production to the economic growth model. The available models were created to describe reality for the industrial era. In order to improve the usefulness of these tools in the age of the digital economy (with the Internet of Things, artificial intelligence algorithms and autonomous vehicles), it is necessary to modify them or replace the existing factors of production with new ones – adapting to new realities. The authors undertake the modification of existing economic growth models by adding digital saturation as an operationalized phenomenon of the digital economy. Additional legitimacy for this idea is provided by calls for expanding traditional models to include a factor representing the digital economy (Li and Shuliang, 2023; Chang et al., 2023).

The verification of hypotheses and research questions will be carried out on the basis of the n+1 factor production function. This is the neoclassical production function in the Nonneman-Vanhoudt growth model in continuous time:

$$Y(t) = A(t)K_1(t)^{\alpha_1} K_2(t)^{\alpha_2} K_3(t)^{\alpha_3} \dots K_n(t)^{\alpha_n} L(t)^{1-\sum_{j=1}^n \alpha_j} \quad (6.17)$$

Where:

$Y(t)$ – The value of gross domestic product in year t (t=2012,...,2019) at constant prices 2017=100);

$A(t)$ – Total factor productivity in year t; the product that can be produced from unit inputs of capital (K_i) and labor (L);

$K_i(t)$ – capital input (physical³, human, digital) in year t;

$L(t)$ – number of workers in year t ;

$\alpha_j \in (0;1)$ and $1 - \sum_{j=1}^n \alpha_j \in (0;1)$ $j=1, \dots, n$ – the elasticity of production with respect to j -th input of capital goods and the j -th input of labor, respectively.

In order to reduce the function to linear form with respect to growth rates, equation (6.17) was divided by the number of workers L

$$\frac{Y(t)}{L(t)} = A(t) \frac{K_1(t)^{\alpha_1}}{L^{\alpha_1}} \frac{K_2(t)^{\alpha_2}}{L^{\alpha_2}} \frac{K_3(t)^{\alpha_3}}{L^{\alpha_3}} \dots \frac{K_n(t)^{\alpha_n}}{L^{\alpha_n}} \quad (6.18)$$

The relationship $A_t = A_0 e^{gt}$ (where $A_0 > 0$ is the initial level of total factor productivity) was used

$$\frac{Y(t)}{L(t)} = A_0 e^{gt} \frac{K_1^{\alpha_1}(t)}{L^{\alpha_1}} \frac{K_2^{\alpha_2}(t)}{L^{\alpha_2}} \frac{K_3^{\alpha_3}(t)}{L^{\alpha_3}} \dots \frac{K_n^{\alpha_n}(t)}{L^{\alpha_n}} \quad (6.19)$$

The values thus obtained were logarithmized on both sides:

$$\ln(y(t)) = \ln(A_0 + gt + \alpha_1 \ln(k_1(t)) + \alpha_2 \ln(k_2(t)) + \alpha_3 \ln(k_3(t)) + \dots + \alpha_n \ln(k_n(t))) \quad (6.20)$$

Where:

$$y(t) \equiv \frac{Y(t)}{L(t)} - \text{Gross domestic product per worker (in labor productivity) in year } t$$

($t=2012, 2013, \dots, 2019$);

$$k(t) \equiv \frac{K(t)}{L(t)} - \text{Capital good (in. technical armament of labor) per worker in year } t;$$

α_j is defined as in the previous equations (6.17) and (6.18).

Equation (20) was then differentiated after time and a function of the form was obtained:

$$\frac{y_i(t)}{y_i(t)} = g + \alpha_1 \frac{k_{1,i}(t)}{k_{1,i}(t)} + \alpha_2 \frac{k_{2,i}(t)}{k_{2,i}(t)} + \alpha_3 \frac{k_{3,i}(t)}{k_{3,i}(t)} + \dots + \alpha_n \frac{k_{n,i}(t)}{k_{n,i}(t)} \quad (6.21)$$

Where:

$g > 0$ – exogenous rate of technical progress in the Hicks sense⁴

In the search for the closest real-world explanation of the relationship between digitization and economic growth, the model described by equation (6.21) was tested in two variants. The first approach involves creating a 14-factor model, taking into account 11 variables describing the digital economy. In it, parameter values are estimated separately for analytical groups: EU28 GDP1, GDP2, GDP3, GDP4.

The second variant extends the described model with Schumpeter's assumptions of creative destruction by adding variables describing the size structure of economic agents in a given market.

Initially, variants with a single factor describing the digital economy were also considered, where the taxonomic indicator of digital saturation played this role. Similarly, separate variants were created and tested in which only supply or demand variables were included (the variables described in Chapter 5). However, in the aforementioned cases, satisfactory results and statistical significance were not obtained.

The first option breaks down the digital economy into individual factors – using the 11 macroeconomic variables described in Chapter 5. A twelfth variable was added to this set to describe the digital economy, that is, the value of the ICT sector in a given economy (estimated based on the value of GDP and the percentage of the ICT sector in the economy). This was to show the size of the sector as well as its relevance to the overall economy. The parameters were estimated using the OLS method for $m=14$. Table 6.6 shows the estimation results for the EU28 countries and GDP1, GDP2, GDP3 and GDP4.

The decision was made to switch from continuous to discrete mode in the analysis of the production function, using logarithmic increments instead of the time derivative of the logarithm. This stems from the need to adapt the theoretical model to the realities and limitations of empirical data, which are usually available at discrete intervals. The use of logarithm increments facilitates the estimation and interpretation of models in the context of real economic processes that take place at specific points in time, rather than continuously. This approach increases the consistency of the analysis with economic realities, facilitating the use of standard econometric methods and improving the applicability of the research in economic practice.

$$\begin{aligned}
 y_t = & g + \alpha_1 \Delta \ln k_t + \alpha_2 \Delta \ln h_t + \alpha_3 \Delta \ln d_{1t} + \alpha_4 \Delta \ln d_{2t} + \alpha_5 \Delta \ln d_{3t} \\
 & + \alpha_6 \Delta \ln d_{4t} + \alpha_7 \Delta \ln d_{5t} + \alpha_8 \Delta \ln d_{6t} + \alpha_9 \Delta \ln d_{7t} + \alpha_{10} \Delta \ln d_{8t} \\
 & + \alpha_{11} \Delta \ln d_{9t} + \alpha_{12} \Delta \ln d_{10t} + \alpha_{13} \Delta \ln d_{11t} + \alpha_{14} \Delta \ln d_{12t}
 \end{aligned} \tag{6.22}$$

Where,

$\Delta \ln d_{it}$ – the increment of the logarithm of the share of ICT specialists in the total workforce, divided by the number of workers in the i -th country in year t ;

- ΔInd_{2t} – the increment of the logarithm of ICT’s share of GDP divided by the number of employed, in the i-th country in year t;
- ΔInd_{3t} – the increment of the logarithm of ICT imports, divided by the number of workers, in the i-th country in year t;
- ΔInd_{4t} – the increment of the logarithm of ICT exports, divided by the number of workers, in the i-th country in year t;
- ΔInd_{5t} – the increment of the logarithm of the share of companies employing ICT specialists, divided by the number of employees, in the i-th country in year t;
- ΔInd_{6t} – the increment of the logarithm of ICT R&D spending, divided by the number of employees, in the i-th country in year t;
- ΔInd_{7t} – The increment of the logarithm of the value of e-commerce sales, divided by the number of employees, in the i-th country in year t;
- ΔInd_{8t} – The increment of the logarithm of the share of Internet users interacting with public authorities, divided by the number of workers, in the i-th country in year t;
- ΔInd_{9t} – the increment of the logarithm of the share of people working remotely, divided by the number of people working, in the i-th country in year t;
- ΔInd_{10t} – the incremental logarithm of the share of people using e-commerce, divided by the number of people working, in the i-th country in year t;
- ΔInd_{11t} – the incremental logarithm of the share of the population using online banking, divided by the number of employed, in the i-th country in year t;
- ΔInd_{12t} – the increment of the logarithm of the value of the ICT sector in the economy divided by the number of employees, in the i-th country in year t;
- y_t – Gross domestic product per worker (i.e., labor productivity) in the year;
- Δlnk_t – The incremental logarithm of physical capital;
- Δlnh_t – The growth of the logarithm of human capital;
- g – The exogenous rate of technical progress in the Hicks sense;
- α_j for $j = 1, \dots, 14$ – elasticity of output with respect to the j-th input of physical capital (α_1), human capital (α_2) and variables representing digital saturation ($\alpha_3, \dots, \alpha_{14}$)

Thus, it is assumed that the process of labor productivity is described by the above n-factor production function, in which:

- infrastructural capital includes: $\Delta Ind_2, \Delta Ind_6, \Delta Ind_{12}$;
- human capital includes: $\Delta Ind_1, \Delta Ind_9$;
- social capital includes: $\Delta Ind_5, \Delta Ind_8, \Delta Ind_{10}, \Delta Ind_{11}$;
- relational capital includes: $\Delta Ind_3, \Delta Ind_4, \Delta Ind_7$.

The parameters of equation (6.22) were estimated using OLS. Table 6.6 shows the estimation results for the EU28 countries and GDP1, GDP2, GDP3 and GDP4.

Analysis of the parameters estimated in variant one, seen in Table 6.6, allows the following conclusions:

- The rate of technical progress in 2012–2019 is negative (-1,2%; -0,9%);

Table 6.6 Results of parameter estimates of equation (6.22)

<i>Explanatory variable</i>	<i>EU28</i>	<i>GDP1</i>	<i>GDP2</i>	<i>GDP3</i>	<i>GDP4</i>
Rate of technical progress	-0,0089 ***	-0,0114 ***	-0,0118 ***	-0,0104 ***	-0,0082 **
$\Delta \ln$ (Physical capital/L)	0,2495 ***	0,3241 ***	0,2772 **	0,1876 ***	0,3334 ***
$\Delta \ln$ (Human capital/L)	0,2147 ***	0,0608	0,0598	0,3543 ***	0,5868 ***
$\Delta \ln$ (Share of ICT specialists in total workforce/L)	0,05388 ***	0,0179	0,0731	0,0138	-0,0422
$\Delta \ln$ (ICT share of GDP/L)	-0,6768 ***	-0,6475 ***	-0,5282 ***	-0,8195 ***	-1,0229 ***
$\Delta \ln$ (ICT Imports/L)	-0,0041	0,005	0,0043	-0,0159 *	-0,0235 **
$\Delta \ln$ (ICT Exports/L)	0,0011	0,0055	0,0106 **	-0,0012	0,0009
$\Delta \ln$ (Share of companies employing ICT specialists/L)	0,0045	-0,0057	0,017	0,012 *	0,0042
$\Delta \ln$ (ICT sector R&D expenditures/L)	0,004	-0,0147	0,0094	0,0061	0,0008
$\Delta \ln$ (E-commerce sales value/L)	0,0028	0,0038	0,0186	-0,0086	0,0063
$\Delta \ln$ (Participation of Internet users in dealing with public authorities/L)	0,008 **	0,0199	0,0012	0,0013	0,0243 ***
$\Delta \ln$ (Share of people working remotely/L)	-0,0028	0,0138	-0,0147	0,0003	-0,0014
$\Delta \ln$ (Share of people using e-commerce/L)	0,0038	0,0532 *	0,0276	0,0009	-0,0601 ***
$\Delta \ln$ (Share of population using online banking/L)	0,0193 **	-0,0332 ***	0,0668	0,0159	0,0186 **
$\Delta \ln$ (ICT/L sector value)	0,7075 **	0,6908 ***	0,6215 ***	0,9012 ***	1,0466 ***
R^2	0,7798	0,7658	0,8166	0,9352	0,9247
Corrected R^2	0,7587	0,6444	0,7216	0,9016	0,872
Number of observations	161	42	42	42	35
F-statistic	36,9411	6,3064	8,5861	27,8298	17,5494

Source: Own study.

- The ICT sector's share of GDP, the value of the ICT sector, physical capital and human capital received the highest parameter values;
- The lowest value of the function parameters was obtained by the share of people working remotely, R&D expenditures of the ICT sector, ICT imports and the value of e-commerce sales;
- A high significance level of R^2 (0,77 to 1,05) and adjusted R^2 (0,64 to 0,9) were achieved;
- The highest matching (according to adjusted R^2) was achieved by the GDP3, GDP4 and EU28 groups.

The analysis of individual parameters indicates that the effect of human capital on economic growth increased as one moved to poorer and poorer analysis

groups (see hypothesis two). This may be related to the so-called catch-up effect, where a country starting out with a low baseline absorbs ready-made and proven solutions from abroad. At the same time, countries in the groups with the highest GDP per capita have a highly skilled workforce, an educated population and an education system that is sufficiently developed that any investment in it yields lower marginal gains. Indeed, for these countries, further upgrading of human capital requires the acquisition of even more complex skills and the generation of new, innovative ideas.

In order to answer which side of the digital economy, demand or supply side, is more important for economic growth, the authors analyzed the parameter values and the significance of the variables in the model. In the case of statistical significance, the supply-side dominates. In the case of the demand side of the digital economy, in two analysis groups (GDP2, GDP3), none of the demand variables proved statistically significant.

Negative and near-zero values of the estimated rate of technical progress may indicate the observed secular stagnation of economies, which relates to the second research question. However, it should be borne in mind that the study included only the short period 2012–2019. This means that an analogous analysis for a longer series may indicate different dynamics of technical progress.

The third research question is about the most relevant variables in terms of economic growth that measure the development of the digital economy. The results of the model (Table 28) indicate that the most important variables are the value of the ICT sector, the share of ICT professionals in the total workforce, the share of the population using online banking, the share of people using e-commerce and the share of people using the Internet to interact with public authorities. At the same time, the share of ICT in GDP has a high (antagonistic) impact. These observations prompt the first general recommendation for digital policy in terms of priority development areas.

6.5 The digital economy and creative destruction – an empirical analysis

As contained in the title of this research work, Schumpeter's theory implies the emergence of creative destruction. This is a change in market equilibrium caused by the emergence of an innovation that gives significant advantages to the entrepreneur who introduced it to the market. His innovation allows him to increase his market share at the expense of less innovative companies by which he "cleans the market" of the least well-managed enterprises. The result is a new equilibrium point at which higher incomes are achieved which, for the same number of workers, translates into higher earnings for workers and growth in the economy and productivity. In order to understand creative destruction well, it is necessary to list the main assumptions:

- An innovation is emerging that is radically changing the business environment;
- New companies are created based on it, which over time create entirely new sectors;

- Some sectors are marginalized and eliminated, while the rest are gradually transformed;
- Such innovation is most served by oligopolies made up of corporations that, with their financial and human resources backgrounds, can bear the risk of innovation research (structured capitalism).

In order to verify the question of how the size structure of businesses in a given domestic market affects the level of development of the digital economy, equation 22 was modified by adding the percentage of businesses divided into micro (up to 9 employees), small (up to 50), medium (up to 250) and large (more than 250 employees). For such a modified production function, parameter values were estimated using the OLS method. The estimation results for the EU28, GDP1, GDP2, GDP3 and GDP4 group countries are shown in Table 6.7.

The analysis of the parameters estimated for the five analytical groups of the second model variant shown in Table 6.7 allows the following conclusions to be drawn:

- In all cases, very high model significance was obtained (at over 0.93);
- The rate of technical progress is positive in most cases, but close to zero for all variants;
- The share of ICT in GDP is almost as important as the value of the sector's output, except that they have opposite signs. This means that dependence in the form of greater reliance on digital technologies for GDP does not help growth. However, the sheer value of the ICT sector (in the model adjusted for the number of employed) is already significantly helping the country grow;
- Again, exports and imports, R&D spending or remote work have little impact on economic development;
- An interesting trend is the growing importance for economic development of the number of small entities. Microenterprises have the largest impact on economic growth, followed by small and medium-sized companies, respectively. This is an inverse impact of the size of small and micro firms than Schumpeter's theory would suggest.

The estimation of parameter values for the five groups (EU28 and GDP1-4), including as explanatory variables and the size structure of enterprises in a country, provides important information from the perspective of answering the first and second research questions.

The first question relates to the digital economy's fulfillment of the prerequisites to be called creative destruction according to Schumpeter's theory. The emergence of a new digital sector (ICT) triggered by the emergence of radical innovation (the Internet) is evident. An important assumption in the Schumpeterian model is also the leading role of entrepreneurs, who are the most innovative in the oligopoly called structured capitalism. The results from the developed model indicate the opposite. The larger the share of smaller players in an economy, the stronger the impact on economic growth. This may indicate that the digital economy is different

Table 6.7 Results of equation parameter estimates taking into account the size structure of enterprises

<i>Explanatory variable</i>	<i>EU28</i>	<i>GDP1</i>	<i>GDP2</i>	<i>GDP3</i>	<i>GDP4</i>
Rate of technical progress	-0,0001	0.0011	-0.0007	0,00004	0.0019
$\Delta \ln$ (Physical capital/L)	0.0067	-0.0215	0.0014	0.0179	-0.0159
$\Delta \ln$ (Human capital/L)	0.0095	0.0219	0.0026	0,000049	-0.0274
$\Delta \ln$ (Share of ICT specialists in total workforce/L)	-0.0021	-0.0176	0.0061	-0.0024	-0.0053
$\Delta \ln$ (ICT share of GDP/L)	-0.9935 ***	-0.8975***	-0.9785 ***	-1.0009 ***	-0.972 ***
$\Delta \ln$ (ICT Imports/L)	-0.0011	-0.0029	0.0003	-0.0024	0.0001
$\Delta \ln$ (ICT Exports/L)	0.0005	0.0008	0.0022 **	0,00004	0.0017
$\Delta \ln$ (Share of companies employing ICT specialists/L)	-0.0002	0.0059	0.0007	0.0009	-0.0031
$\Delta \ln$ (ICT sector R&D expenditures/L)	0.0006	-0.0047	0.0017	0.0008	-0.0014
$\Delta \ln$ (E-commerce sales value/L)	0.0018 *	0.0035	0.0068 **	0.0003	-0.0018
$\Delta \ln$ (Participation of Internet users in dealing with public authorities/L)	0.0008	0.0018	0.0022	0.0004	-0.001
$\Delta \ln$ (Share of people working remotely/L)	-0.001	0.0033	-0.0034	-0.0021 *	-0.0029
$\Delta \ln$ (Share of people using e-commerce/L)	-0.0016	0.0182	-0.0047	-0.0027 *	-0.0014
$\Delta \ln$ (Share of population using online banking/L)	0.0009	-0.0156	0.0007	-0.0023	0.0003
$\Delta \ln$ (ICT/L sector value)	0.994 ***	0.9034 ***	0.9924 ***	0.9987 ***	0.9664 ***
$\Delta \ln$ (Share of large enterprises/L)	0.0102 **	0.0197	0.0025	0.0075	0.0238 *
$\Delta \ln$ (Share of medium-sized enterprises/L)	0.0234 ***	0.0211	0.0168	0.0273 ***	0.0055
$\Delta \ln$ (Share of small enterprises/L)	0.0417 ***	0.0386 **	0.042 ***	0.0449 ***	0.0417 ***
$\Delta \ln$ (Share of micro enterprises/L)	0.896 ***	0.7968 ***	0.8863 ***	0.913 ***	0.9661 ***
R^2	0,9913	0.9589	0.9986	0.9982	0.9978
Corrected R^2	0,9901	0.9268	0.9967	0.9967	0.9939
Number of observations	144	42	33	40	29
F-statistic	791,5966	29,8362	543.4892	650.6864	252.6859

Source: Own study.

from other industrial revolutions and radical innovations, in which large companies were the main actors

Here one can move smoothly to the second research question, which touches on the problem of declining economic growth and the risk of achieving secular stagnation. This is because it contradicts the assumptions of creative destruction from question one. If the current state is secular stagnation then further development of the digital economy, regardless of its pace, would not significantly affect dynamic productivity growth. This is indicated by the estimated rates of technical progress which are close to zero in 2012–2019 for the countries analyzed. This is a very short time frame for the study, which is determined by the availability of data. When having a 15- or 20-year time series, the results could differ and indicate new correlations.

These results also bring us closer to the verification of hypothesis three, which concerns the spread of the observed productivity growth from the ICT sector to the entire economy. According to the authors, overcoming the current state of stagnation by achieving a higher rate of technical progress and productivity growth in sectors other than ICT and trade will be achieved by further digital saturation. The positive effects are not as visible at present because of the fact that the ICT sector in the European Union employs about 4,5% of the workforce, while trade employs about 16,5%. Thus, the productivity growth currently observed is due to the development of the digital economy in only 21% of the workforce (or more precisely, its core and narrow definition described in Chapter 1).

6.6 Summary

The purpose of this chapter was to study the properties of the relationship between variables describing digital saturation and economic growth using a modified production function. The main objective, which resounds from the title of this work, is to try to answer the question: whether the digital economy fits into the Schumpeterian description of creative destruction.

According to Schumpeter's theory, it all starts with the entrepreneur who introduces the innovation to the market. He receives a bonus and a temporary monopoly role. Extraordinary profits attract imitators who copy the innovative product leading to the diffusion of the innovation. Companies that reject the innovation or are incapable of implementing it are taken over or go bankrupt, and their resources are seized by the remaining players. The result is a new point of market equilibrium, where earnings are higher, economic growth is observed and productivity is booming.

While this whole description worked perfectly in the era of the steam engine, electricity and computerization (the first three industrial revolutions), the digital transformation seems to be escaping this theoretical framework. Since the 1990s, that is, the development of the Internet, there has been a decline in productivity dynamics and a stagnation of economic growth rates. This raises the question: is the digital economy a creative destruction and are highly developed economies approaching the limit of growth opportunities (secular stagnation)?

To this end, a review of neoclassical economic growth models was conducted with the aim of selecting the model best suited to the analysis of the digital economy in light of Schumpeter's creative destruction. The Solow model, which takes into account the stock of labor, physical capital and technical progress, was found to be inadequate by omitting other aspects of capital stock and by the exogeneity of technical progress. The Mankiw-Romer-Weil model, which extends the production function to include the stock of human capital and endogenizes technical progress, makes it possible to measure changes in the in the information society. However, for a full analysis of the demand and supply side of the digital economy, it is necessary to place there additionally the capital stock represents the digital economy ("digital capital"). For this reason, the best for this seems to be a modified Cobb-Douglas-type production function used in the Nonneman-Vanhoudt model.

In addition, in order to understand the spatial variation in the level of development of the digital economy, a taxonomic index of digital saturation was constructed. It uses 11 macroeconomic variables on the demand and supply side of the digital economy, which were selected and analyzed in Chapter 5. For a more complete and accurate measurement of the level of development of the digital economy, the 23 countries analyzed, representing the entire European Union (EU28), were divided into 4 quartile groups according to the level of GDP per capita PPP in 2022. The authors see potential problems arising from this division key such as the heterogeneity of the groups of countries in terms of the level of urbanization, the number of cities, the level of social development.

The use of two research methods (taxonomic analysis and a modified neoclassical production function) made it possible to verify and most of the research questions and hypotheses posed in the introduction of the chapter.

Taxonomic analysis was used to verify hypothesis one and two. Hypothesis one assumes the existence of a digital division of Europe, which is different from the traditional one made according to the level of GDP per capita. The study shows that Denmark, Finland and the Netherlands play a leading role in Europe in terms of both the traditional division (GDP) and the digital saturation index. Countries such as Malta, the United Kingdom, Hungary, Croatia, Latvia and Slovakia show higher levels of digital saturation compared to their traditional wealth. It is also worth noting that Italy and Estonia are countries with extremely mixed results. Italy's economy, despite its average GDP level, is in the lower digital category, while Estonia, with lower traditional wealth, is in the group with higher levels of digital development. For the EU28 group, the prominent role of the Baltics, the Czech Republic, Hungary and Malta is evident, outperforming countries traditionally considered richer like Italy, Spain and Greece in digital terms

The hypothesis is that there are large differences in digital saturation between countries within groups of countries with similar levels of GDP per capita. For this purpose, a taxonomic analysis in four analytical groups was used.

In the GDP1 (Austria, Belgium, Denmark, Finland, Germany and the Netherlands), the highest weight in the indicator was given to the share of companies employing ICT professionals and the share of ICT in GDP. The lowest, on the other hand, were ICT exports and imports. Within this group, three subgroups are

evident, with Finland, the Netherlands and Denmark performing highest; Belgium and Germany achieving average values and Austria widening the gap from the rest of the group. At the same time, Belgium leads the dynamics in GDP1 group.

In the GDP2 group (Czech Republic, France, Italy, Malta, Slovenia and the United Kingdom), ICT exports and imports were also the least significant. Among the most significant variables are the share of firms employing ICT specialists and the share of these specialists in total employment. The leader of the group is the United Kingdom. It is followed by Malta, which has equaled France in the value of the indicator. The most dynamic development of the digital economy was achieved in this group by the Czech Republic, which was on the level of Slovenia in 2012–2019. The lowest values were achieved by Italy, which in every year analyzed is far behind the rest of the group.

In the GDP3 group (Estonia, Hungary, Lithuania, Poland, Romania and Spain), the significance of variables in the taxonomy index is similar to the GDP1 group. Values for virtually all countries are strongly similar, and between 2012 and 2019 the differences are leveled out. The evens are Estonia (which, as of 2014, is visibly distancing itself from the rest of the countries and moving into a leading position) and Romania (which is achieving a visibly lower level of digitization relative to the rest of the GDP3 group).

In the GDP4 group (Bulgaria, Croatia, Greece, Latvia and Slovakia), the most significant variables are similar to the GDP1 and GDP3 groups. At the same time, among the variables with the lowest relevance to the indicator are remote work, online banking, ICT exports and e-commerce. The leader of the group achieving the highest values of the digital saturation index is Slovakia. Bulgaria and Latvia achieved the highest dynamics in 2012–2019. The exception is Greece, which saw a 14% decrease in the value of the index during the period under review.

Hypothesis two focuses on the existence of complementarity between human capital and digital saturation that can determine economic growth. Data analysis shows that high levels of traditional wealth often go hand in hand with developed human capital and advanced digitization, as seen in countries such as Denmark, the Netherlands and Finland. Similar patterns are observed in Poland and Bulgaria. Germany, Austria and, to a lesser extent, Romania deviate from this trend, scoring higher in traditional economic rankings than in human capital and digitization. Latvia is the only country that scores low on GDP relative to human capital and digitization, which may indicate its growth potential. The Czech Republic and France have lower levels of human capital relative to GDP and digitization, as do the United Kingdom, Malta and Croatia. The performance of the Hungarian and Estonian economies is inflated by digitization, but understated by human capital. Lithuania, Spain, Italy and Greece have low digital saturation relative to GDP and human capital. The analysis supports the hypothesis that high GDP, digitization and human capital support economic growth, but countries with problems in digitization, despite high human capital, may experience economic stagnation.

A modified production function used in the Nonneman-Vanhoudt economic growth model was used to answer the question of the impact of digitization on economic growth, the productivity paradox and secular stagnation, while noting

the weakness of the methodological apparatus constructed in the industrial era and used to measure the digital economy. However, a review of other studies prompts the use of the neoclassical model as a basis for further research. Significantly, there is an exceptionally strong emphasis on the perspective of digitization – the authors measure the strength of its impact on economic growth.

The analysis used two variants of the production function, differing in the number and structure of the variables. Parameter values are estimated for groups: EU28, GDP1, GDP2, GDP3, GDP4.

The first option was to use all 11 variables, which were used to create a taxonomic index of digital saturation. It reached high values of significance R^2 (0.64–0.9). At the same time, the rate of technical progress was negative and close to zero, which may indicate short-term stagnation. In light of the second research question, regarding the emergence of secular stagnation in European countries, these are worrying results. However, what should be noted is the short time series (2012–2019), which illustrates only a small slice of the dynamics of change. This means that with a longer, 20–30-year time series, the stagnation in question may not be present.

The value of the ICT sector, ICT's share of GDP, physical capital, human capital and the share of ICT professionals in total employment were the most significant parameters. The least significant were the prevalence of remote work, e-commerce sales, ICT sector R&D spending and ICT imports. Trade issues proved to be of little importance, including imports and exports, although the former was still more likely to prove statistically significant for economic growth. The role of e-government is high for GDP1 and GDP4 countries, online banking is important for GDP2 and the prevalence of online shopping is important for GDP1 and GDP2 countries.

At the same time, the results of the analysis of changes in the value of the taxonomic index of digital saturation can be used to answer the third research question. In the analyzed period 2012–2019, the highest growth dynamics were achieved by Bulgaria, Latvia, Poland, Estonia and Romania. It is these countries that should be a model for the design of innovation and digital policies among the countries of the New Union. At the same time, it would be appropriate to analyze the policies of the United Kingdom, Finland, Denmark and the Netherlands – as the most effective examples of policies for the Old Union countries.

In addition, human capital has a stronger impact on economic development in poorer countries through the catch-up effect. At the same time, in the richest countries, the marginal gains from human capital investment are lowered by highly developed society and education in them. In the context of complementarity hypothesis two, this means that countries with lower levels of GDP per capita need to intensively develop both human capital and digital saturation, as neglect of either sphere will reflect in a deceleration of development dynamics and thus stop these countries from catching up with the rich countries of the old EU.

Since one of the assumptions of creative destruction in addition to the introduction of innovation is oligopolization, which is conducive to innovation, a second variant was created, taking into account the size structure of business entities in a

given national market, which helps answer the first research question. This resulted in a very high significance of the models. Again, values of the rate of technical progress were obtained close to zero. The lowest relevance to the development of the digital economy are ICT exports and imports, remote work and R&D spending by the ICT sector. ICT sector output and the ICT sector's share of GDP (which has an antagonistic effect on economic growth) turned out to be the most important. The largest impact on economic growth in the analyzed variants is the share of micro, small and medium-sized companies, respectively. Thus, these are results opposite to Schumpeter's assumptions. Despite the emergence of radical innovation and the development of a new sector, there is still no expected increase in productivity. In addition, micro companies rather than corporations are the most conducive to economic development based on the digital economy.

The results also serve to verify the fourth hypothesis regarding the superiority of the supply side of the digital economy over the demand side. Higher statistical significance of variables was obtained by the supply side representing the infrastructure side and production side. For the GDP2 and GDP3 groups, the dominance of the supply side over the demand side was the highest.

The results from both options indicate that the digital economy is still in the installation phase. In the course of its maturation, the importance of the demand side of the digital economy should grow. With its further development, there will also be a full transformation of the traditional sectors of the economy, which will spill over into sectors other than IT and trade, resulting in a leap in the productivity of the entire economy. The transition to the development phase of the digital economy will increase the role of human capital and the demand (social) side for further digital and economic development. At the same time, more sectors will be fully digitized and a dynamic and leapfrogging increase in productivity will be observed there. This growth will not be the same for every sector; however, the current stagnation is temporary and the development of technologies such as artificial intelligence will allow a radical increase in employee productivity in every industry. The rapid development of generative artificial intelligence in the form of ChatGPT, Microsoft Copilot, Midjourney or Google Gemini, observed since 2023, could be the beginning of the digital economy's transition to the next phase of development. However, an adequate data reporting period will be needed to conduct relevant research in this area.

Notes

- 1 John Bates Clark's marginal theory of distribution has been widely criticized in the context of modern economic models. Tokarski and Zachorowska-Mazurkiewicz (2016) point out the significant discrepancies between Clark's original assumptions and modern applications of his theory, which often simplify real economic conditions without taking into account the full dynamics and interactions between different factors of production. The authors emphasize the theory's lack of empirical verifiability in real economic conditions and point out the mathematical and theoretical inconsistency of models based on its assumptions.

As a result, Clark's theory, while theoretically offering a mechanism for distributing income among factors of production, in practice does not provide optimal solutions, which indicates the need to revise it and adapt it to modern economic conditions.

- 2 A component of the HDI will be used to measure the level of human capital development. The use of the overall HDI would not be possible by the potential correlation of variables (the component of the HDI is gross national income per capita PPP).

Recognizing the crucial role of education for human capital development, the authors made the choice of using the expected length of education for children entering school. This variable, according to the authors, determines the potential of subsequent generations to increase productivity, innovation and economic growth. Data were obtained from Human Development Reports (United Nations).

- 3 The author was not able to obtain data on physical capital, which forced the estimation of values in accordance with Aiello and Scoppa (2000), Wisła and Nowosad (2020) and Tokarski (2000, 2001, 2003, 2008, 2009). Owing to the availability of investment data (Gross Fixed Capital Formation), the maximum period for estimating physical capital for 2012–2019 was $T = 15$ (the maximum range of available dates was 1995–2019; no older data were available for Bulgaria, Hungary, Latvia Lithuania, Malta and Romania).

The values were then adjusted for inflation. Data were obtained from: <https://data.oecd.org/gdp/investment-gfcf.htm>.

- 4 In the context of rates of technological progress, different approaches to modeling their impact on output are important for economic analysis. Technological neutrality according to Harrods assumes that technological progress increases the productivity of labor without changing the capital intensity of production, which promotes economic growth by improving the efficiency of labor without increasing the capital-output ratio. Technological neutrality, on the contrary, according to Hicks, is characterized by the fact that an increase in the efficiency of production does not affect the relative efficiency (ratio of marginal productivity) of labor to capital, which allows the productivity of all factors of production to increase evenly, keeping their relative prices constant. The general concept of neutral technological progress emphasizes that innovation does not favor any of the factors of production over others, which promotes an increase in the overall efficiency of the production process without preferring labor over capital or vice versa. Understanding these differences is key in economic modeling and analyzing the impact of innovation on economic growth, highlighting the universal benefits of of technological progress for the economy as a whole.

Key findings

The digital economy is a phenomenon that is shaping the economic landscape of the 21st century. The emergence and popularization of the Internet have created space for the development of a wide range of digital technologies, virtual platforms and digital products, driving the transformation of entire economies. The digital economy serves as an umbrella term that encompasses the markets for digital technology, telecommunications, e-commerce and data processing.

The emergence of the digital economy is a natural consequence of the development of the knowledge economy, in which structured digital information is becoming a key factor in the qualitative advancement of civilization. The paradigm shift in production factors – where digital data is replacing traditional resources and automation along with communications infrastructure are becoming the new capital – reflects the profound transformation brought about by digitization. Understanding these changes requires considering at least four perspectives: economic, technological, regulatory and social.

The digital economy, understood as a technological sector (Core) that influences economic relations (narrow scope) and transforms traditional economic sectors, is centered around technologies such as robotics, cloud computing, the Internet of Things, 3D printing and artificial intelligence. Hence, the application of the achievements of innovation economics has become the primary canvas for theoretical inquiry and empirical verification.

The clash between Schumpeterian theory and the emerging digital economy is deeply puzzling, as, despite increased digitization expenditures, a decline in productivity dynamics has been observed in highly developed countries. This productivity paradox arises in countries with high R&D spending and extensive digital infrastructure, even amid falling ICT prices. This situation – despite theoretical assumptions suggesting that the development of the digital economy should stimulate productivity growth – raises questions about the effectiveness and actual impact of digitization on the economy. One factor that may help explain this paradox is the phenomenon of secular stagnation.

Secular stagnation is associated with an aging population, rising inequality and declining innovation in highly developed countries. Contributing to this are

the destabilization of the pension system and excessive social stratification, both of which reduce the growth of the savings rate at the expense of investment and consumption. This, in turn, inhibits demand as well as economic and productivity growth. In this context, the digital economy – despite being a source of innovation – may not generate the expected productivity gains due to these broader macroeconomic factors.

Digital transformation is ubiquitous and affects everyone – not only through changes in economic sectors, but also through the growing importance of digital skills, which are becoming crucial in the labor market. Therefore, the development of the digital economy requires investment not only in technology, but also in human capital, education and society’s adaptability to new digital conditions.

The following generalizations were derived from the empirical analysis of the digital economy, with a breakdown into its demand and supply sides. First, in the case of demand variables, the traditional division of Europe remains evident. However, from the supply-side perspective, countries in the eastern part of the EU – traditionally considered poorer – such as Estonia, Latvia, Hungary and Malta already exhibit above-average digital saturation scores.

Second, analysis using the author’s taxonomic index of digital saturation made it possible to observe spatial and temporal changes across EU countries. Nations such as Bulgaria, Latvia, Poland, Estonia and Romania recorded the highest rates of change in the index, with increases in digital saturation ranging from 32% to 68% between 2012 and 2019. In contrast, the lowest dynamics were observed in “old EU” countries such as Austria, the United Kingdom, Greece and Denmark. If this trend continues, it could lead to a polarization along the development axis of “digital Europe”, as measured by levels of digital saturation. While high dynamics may reflect a catch-up effect and progressive convergence, when combined with the upward movement of the New Union countries in the digital saturation rankings, they suggest the higher effectiveness of innovation and digitization policies in countries like the Czech Republic and Estonia compared to those in Italy or Greece.

Third, the taxonomic analysis across the four groups also revealed significant internal variation in the level of digital saturation among countries with similar levels of traditional wealth. In particular, Austria, Italy, Romania and Greece stood out, as their performance was objectively much weaker than that of the other countries within their respective groups.

Fourth, the productivity paradox – that is, the decline in productivity growth dynamics despite the development of the digital economy – may indicate the ongoing maturation of this phenomenon, with the full positive impact on productivity likely to emerge only at a later stage of development. The concept of secular stagnation is presented as an alternative explanation, suggesting that highly developed countries may be undergoing persistent macroeconomic changes that are suppressing economic growth dynamics.

Fifth, although digital transformation introduces technological innovations that should generate new value chains and industries and accelerate economic development, the reality of today’s digital economy appears to be more complex. In line

with Schumpeter's theory, a new sector has emerged around a radically innovative technology – the Internet – and the subsequent development of technologies based on it, such as AI, blockchain and cloud computing. However, the rate of technological progress remains close to zero, despite expectations that creative destruction should result in a surge in productivity. A second point of contention with Schumpeter's theory involves oligopolies, which are typically considered the most conducive environment for innovation. Yet in the context of the digital economy, productivity growth is most significantly driven by small and micro enterprises, suggesting that the key factors of production may differ from those in previous industrial revolutions.

Sixth, one factor holding back economic development in the digital age may be the inadequate development of the digital society. A comparative analysis of digital saturation and human capital revealed a trend toward convergence among most countries, including traditional wealth leaders – supporting the hypothesis of complementarity between the two variables. At the same time, in countries such as Estonia, the United Kingdom and Hungary, digital saturation levels are notably higher relative to GDP per capita and human capital. This suggests the potential superiority of a highly developed digital economy over human capital alone. As a result, “southern countries” such as Spain, Greece and Italy find themselves in a difficult position: their ongoing issues with debt, youth unemployment and economic stagnation cannot be resolved through digitization alone. These countries also exemplify cases of overinvested human capital, which fails to stimulate growth without adequate digital infrastructure. Meanwhile, human capital remains the strongest driver of economic growth in poorer countries, placing increased pressure from the new EU countries on those in the south. The weaker impact of human capital on wealthier EU nations may stem from the already well-developed national education systems and the presence of highly skilled labor forces, which limit marginal gains even with substantial investments.

Thus, the current state of stagnation – observed over an eight-year horizon – may be attributed to the developmental stage of the digital economy. According to its classification, only the core and narrow scope of economic productivity are currently affected, namely the ICT and trade (e-commerce) sectors, which together employ 21% of the EU workforce. As a result, the broader positive impact of digitization on the overall economy has yet to become apparent. As the digital economy continues to mature, it is expected to move beyond the installation phase into a stage of deeper development. When combined with the further penetration and transformation of traditional economic sectors, along with the advancement of human and social capital, this progression could lead to a significant boost in productivity and economic growth. A potential catalyst for this transition into a new era of the digital economy could be the development of artificial intelligence algorithms, which have experienced rapid growth since 2023.

The analyses carried out point to several important directions that can serve as a foundation for further research in the field of digital economics and the impact of ICT on the economy. First and foremost, given the growing role of artificial intelligence in the economy, there is a need for in-depth studies assessing the potential

impact of this technology across various sectors. It is particularly important to examine how automation and intelligent systems will influence labor productivity and the processes involved in digital content creation. This analysis should consider a broad range of industries and economic sectors in order to identify those that stand to benefit most from the integration of AI solutions, as well as to highlight potential risks associated with automation.

In light of the observation that the supply side (digital infrastructure) plays a greater role than the demand side (social acceptance of ICT technology), it is important to conduct further research to determine whether this is a permanent trend or a phenomenon tied to the current stage of digital economy development. This research should also take into account how evolving economic and social conditions influence these dynamics.

In order to gain a deeper understanding of how companies and economies can build competitive advantages through digitization, it is essential to examine the extent to which digital development is driven by internal (endogenous) versus external (exogenous) factors. This will offer clearer insight into the mechanisms underlying the success of digital transformation.

Current research is often constrained by the lack of available long-term data. Therefore, it is recommended that research projects be initiated and supported to collect and analyze long-term time series. Such data would allow for a more accurate assessment of the impact of digitization and ICT on productivity dynamics, as well as the identification of potential periods of stagnation.

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