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The Role of Digitalization in Shaping EU Banks' Business Models

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# I. Abstract

Digital transformation has significantly shaped the European banking sector in the last decades. As banks adjust to changing customer behaviors, competitive pressure from rising fintechs, and evolving regulatory landscape, the way the financial entities operate also changes. This thesis investigates the ways digitalization affects the banking business models in the European Union, focusing on the financial performance of the banking sector of different countries in a rapidly evolving technological landscape. The analysis assesses whether digital transformation affects the business models of the banking sector in the European Union and contributes to the changes of profitability and operational efficiency based on the data for the period 2018-2023.

This Master's Thesis focuses on the following two individual dimensions of result: profitability and operational efficiency on the country level. The contribution to the existing literature is that this study considers important the digital adoption not only by consumers, but also the contribution of internal digital capacity on the supply side as a fundamental driver of digital transformation. The population-side digital adoption is captured by a composite Digitalization Index, while the supply-side indicators are mainly represented by the share of ICT specialists in labor force. Empirically, the approach employs fixed-effects panel regression models and discovers that domestic digital capacity, in particular the proportion of ICT specialists in the workforce, is a determinant of cost efficiency and revenue stability.

The findings indicate that digital transformation impact on the banking sector is significantly enhanced when supported by developing internal competencies, most notably a workforce possessing digital proficiency and able to work in that area. Digital development of the society shows a significant influence on cost efficiency performance metrics, while interconnection with profitability in short run appears not as evident. This suggests that in-house digital capability should be considered as a key priority, while pervasive digital adoption plays a supplementary role in improving the profitability. The deriving policy implications suggest that parallel investment in digital inclusion and in building institutional capacity, specifically workforce training and digital literacy, is necessary.

This thesis offers a comprehensive and applicable contribution to the literature on digital banking by distinguishing between observable digital adoption on the consumer level and embedded digital capabilities provided by the human capital, identifying the latter as an essential factor in promoting sustained transformation and resilience in the European Union banking sector.

# II. Zusammenfassung

Die digitale Transformation hat den europäischen Bankensektor in den letzten Jahrzehnten maßgeblich beeinflusst. Während sich Banken an das veränderte Kundenverhalten, den wachsenden Wettbewerbsdruck durch Fintechs und eine sich wandelnde regulatorische Landschaft anpassen, verändert sich auch ihre operative Ausrichtung. Diese Masterarbeit untersucht, wie sich die Digitalisierung auf die Geschäftsmodelle von Banken in der Europäischen Union auswirkt, mit besonderem Fokus auf die finanzielle Leistungsfähigkeit des Bankensektors in verschiedenen Ländern in einem sich rasant entwickelnden technologischen Umfeld. Die Analyse bewertet auf Basis der Daten für den Zeitraum 2018–2023, ob sich die digitale Transformation auf die Geschäftsmodelle des Bankensektors in der Europäischen Union auswirkt und zu Veränderungen der Rentabilität und der betrieblichen Effizienz beiträgt.

Die Masterarbeit konzentriert sich auf zwei zentrale Ergebnisdimensionen auf Länderebene: Rentabilität und operative Effizienz. Ein Beitrag zur bestehenden Literatur liegt in der differenzierten Betrachtung der digitalen Adoption nicht nur auf der Konsumentenseite, sondern auch auf der Angebotsseite – also in der internen digitalen Kompetenz von Banken – als einem wesentlichen Treiber digitaler Transformation. Die digitale Nutzung durch die Bevölkerung wird über einen zusammengesetzten Digitalisierungsindex erfasst, während die Angebotsseite vor allem durch den Anteil der IKT-Fachkräfte an der Erwerbsbevölkerung repräsentiert wird. Methodisch basiert die Analyse auf Fixed-Effects Panelregressionen und zeigt, dass insbesondere die digitale Fachkompetenz ein entscheidender Faktor für Kosteneffizienz ist.

Die Ergebnisse deuten darauf hin, dass die Wirksamkeit der digitalen Transformation signifikant steigt, wenn sie durch institutionelle Kapazitäten – insbesondere durch eine digital versierte Belegschaft – unterstützt wird. Gleichzeitig zeigt sich, dass die digitale Entwicklung der Gesellschaft einen erheblichen Einfluss auf die Kennzahlen zur Kosteneffizienz hat, während der Zusammenhang mit der kurzfristigen Rentabilität nicht so offensichtlich ist. Dies deutet darauf hin, dass unternehmensinterne digitale Fähigkeiten als Hauptpriorität betrachtet werden sollten, während eine durchgängige digitale Transformation eine zusätzliche Rolle bei der Verbesserung der Rentabilität spielt. Die Implikationen legen nahe, dass parallele Investitionen in die digitale Integration und den Aufbau institutioneller Kapazitäten notwendig sind.

Diese Masterarbeit liefert einen umfassenden und praxisrelevanten Beitrag zur Literatur im Bereich digitales Banking, indem sie zwischen digitaler Adoption auf Konsumentenebene und eingebetteten digitalen Fähigkeiten innerhalb der Institutionen unterscheidet – und letztere als Schlüsselfaktor für Transformation und Resilienz im Bankensektor der EU identifiziert.

# III. Introduction

## 1. Relevance and Research Scope

The accelerated pace of digital technological adoption has been a key driver of the development of contemporary banking, fundamentally transforming financial institutions' operational dynamics and value delivery mechanisms. In the European Union, this development is majorly fueled by a number of factors: the quickly evolving customer needs centered on digital lifestyle, rising competition from financial technology startups and multinational platform-based technology firms, as well as regulatory innovations like the revised Payment Services Directive (PSD2) intended to promote openness and interoperability in the financial landscape and to make markets more efficient and stable (Kolodiziev et al., 2021). Due to the fast-paced introduction of innovations into the competition the traditional banking business model relying on branch-driven operations and interest margin revenues is also experiencing fundamental changes. Digital technologies, such as internet and mobile banking, artificial intelligence-driven credit assessment, big data implementations, blockchain-driven transactions, and cloud-based services have blurred the limitations of the traditional banking and already transitioned from peripheral innovations to fundamental aspects of strategic banking business models, forcing the reconfiguration of existing business models (Carbó-Valverde, 2017, Nguyen et al., 2023, King, 2018).

These technological advances might help enhance cost efficiency, improve real-time interaction experience with customers, and, as a consequence, boost the revenue streams, in particular supposedly through additional non-interest income. At the same time, digital transformation is a capital-intensive process, which poses increased cybersecurity and compliance risks and tends to come with strategic uncertainty, especially for incumbent banks in adapting to competition on the basis of platform business models, hence the effect of IT investments on the profitability might be not necessarily positive (Beccalli, 2007). Additionally, the extent and implications of digitalization vary considerably across EU member states depending on digital infrastructure, regulatory frameworks, and consumer readiness. The variety also complicates policy-making and determination of implications.

Although it is commonly accepted that the digital transformation has a great significance for the banking sector, existing research remains ambiguous on how this adaptation impacts financial performance and business model transformations, particularly in Europe. The means by which banks transform their strategies upon digitalization are significant to various stakeholders, such as the regulators wishing to maintain stability in the system and bankers willing to remain viable in a digital era.

However, the significance of digital transformation is not only to simplify things for the customers and boost sales. The competitiveness and resilience of the European banking system in the long run is currently at stake, as well as its ability to stay relevant within the increasingly digitalized societies. The operational efficiency estimation and comparison is one of the possible ways to measure whether the banking sector might overcome the existing challenges and evolve in accordance with the digital economy needs. In a post-pandemic recovery scenario, the digitalization became essential to rendering financial systems more inclusive, empowering small and medium-sized enterprises, and promoting cross-border financial integration (Kolodiziev et al., 2021).

In order to analyze this swiftly accelerating shift towards the digitalization this thesis examines the influence of digitalization on the evolution of banking business models in the European Union. To advance the understanding of its impact, the digitalization in the banking sector for the research purpose of this thesis is defined as a complex multifaceted process involving the integration of digital technologies into the provision of financial services, business operations, and strategic models. The taken approach not only covers the adoption of digital channels of interaction by retail and business customers (e.g., online banking, mobile banking applications, and fintech platforms) but also the digital innovation infrastructure within a country. More specifically, the digitalization process is considered within the overall perspective of the macroeconomic and institutional setting, bringing together indicators at the national level such as the size of the ICT workforce, developments in digital infrastructure, and the overall "IT climate" facilitating or hampering digital transformation in banking.

The focus of this thesis is thus twofold. First, it empirically examines the degree to which digitalization impacts cost-effectiveness and financial performance within the European Union's banking industry. Second, it investigates the structural determinants that guide the depth and pace at which digital uptake occurs at the national level. This double focus allows for a complex analysis of the ways in which digitalization is not only adopted but also embedded in the changing business models of European banks.

## 2. Research Question and Hypotheses

Building on the theoretical foundations and relevance discussed above, this research aims to explore the effect of digitalization as a multidimensional process on the performance indicators and revenue model of the banking sector in the EU region. While digitalization is widely recognized as an important strategic imperative, its impact on the financial metrics and revenue generation potential of banks has not yet been investigated systematically, particularly with regard

to national differences in digital infrastructure, IT labor availability, and differences in usage patterns among customers.

Consequently, the main research question guiding this thesis is:

In what ways do certain aspects of digitalization, such as internet banking adoption, digital literacy, availability of IT human resources, internet usage, and business e-commerce engagement, affect the profitability and cost efficiency of banks in the European Union?

The theoretical frameworks and empirical findings of the literature on digitization of banking provide convincing explanations of the related issues. The past research has explained the complex relationship between the profitability of banks and their efficiency, whose linkage is influenced by many factors, such as the size of operations, service delivery models, and labor productivity. Recent research shows that digitalization brings about a new dimension of structural change, enabling financial institutions to increase customer engagement, reduce transaction costs, and streamline in-house operations (González et al., 2022, Nguyen et al., 2023).

Drawing on these observations, the higher levels of digitalization, described by increased public uptake of digital banking services, a technologically skilled workforce, and higher adoption of digital business models, should have a positive effect on the profitability of the banking industry, as measured by return on equity (ROE). The cost efficiency component would also be affected, supposing that high levels of societal digital maturity and workforce specialization in information and communication technology (ICT) are associated with higher cost efficiency in the banking sector, which is measured by the cost-to-income ratio (CIR). The hypotheses are underpinned by the idea that digital technologies apart from streamlining operating processes also generate competitive advantages in terms of scalability, data-driven decision-making, and customer relationships, which in its turn leads to the improved financial results.

Based on that, in order to address the research question, the following two testable hypotheses were formulated:

— Profitability Hypothesis (H1): The higher levels of digitalization, marked by greater public engagement with digital bank products, a larger percentage of workforce with IT skills, and greater incorporation of digital business models, exhibit a positive influence on banking sector profitability, as represented by return on equity (ROE).
— Cost Efficiency Hypothesis (H2): Higher levels of societal digitalization, as well stronger technological workforce specializations, are associated with lower cost-to-income ratios

for the banking sector, reflecting higher operational efficiency driven by technology integration and workforce digital competence.

To enhance the validity of the results and reduce potential endogeneity issues, the empirical investigation blends different weighting approaches and conducts sensitivity analyses.

### 3. Structure of the Thesis

This thesis starts with an introduction to the topic, outlining the motivation behind the research, its significance within the framework of continuing digital transformation in the European banking sector, and the formulation of the primary research question and hypotheses. The subsequent section presents a review of the existing literature, examining different conceptual perspectives on digitalization, its measurement across empirical studies, and its potential effects on banking performance and business models.

The empirical section of the thesis delineates the data sources, methodology, and model employed to examine the relationship between digitalization and outcomes at the banking sector level. The estimation results are subsequently discussed, highlighting key findings and drawing conclusions regarding the effects of digital transformation. The thesis concludes with a reflection on limitations, policy ramifications, and opportunities for further research. Supporting materials, including references and technical appendices, are provided at the end.

## IV. Literature Overview

### 1. Traditional Banking Revenue Inflows

Historically, traditional banking institutions have derived the main source of revenue from interest income. This revenue is normally sourced from core lending and deposit transactions that define the bank function of financial intermediation, where banks realize profits from the difference between the interest received from loans and the interest paid to deposits, commonly referred to as the net interest margin (NIM). Thus, interest income is the backbone of the conventional bank system and is a principal determiner of the profitability and well-being of banks in different jurisdictions and market segments (Chiorazzo et al., 2018).

Besides the core income derived from their lending operations, traditional banks consistently gain significant share of the revenue from fees related to non-interest-bearing banking services. More specifically, payment solutions fees and deposit transaction fees have emerged as a critical element of the banks' business models. The services often serve as a significant source of business profits, especially for smaller banks, and act as prime opportunities for banks to extend customer relationships through cross-selling further financial services. Banks have also, in

addition, earned significant fee revenue from fiduciary services and wealth management services, serving both corporate customers and high-net-worth individuals by managing their assets and delivering individualized financial advisory services.

Over the past decades, the bank revenue sources, most importantly, the net interest margin, have been faced with mounting competitive pressures. The challenges for European banks were the result of increased market competition, changing regulatory environments, low interest rates persisting for an extended period, and changing clients' expectations. European banks responded to all these challenges by attempting to diversify income sources, and the result has been a sharp increase in revenue from non-interest earning activities. Empirical evidence widely supports this: the share of non-interest revenue for European banks has increased substantially, rising from around 28% in the early 1990s to nearly 40% in the early 2000s (Goddard et al., 2007). This transition not only reflects an adjustment by banks to responding to market conditions, but it is also indicative of much broader changes occurring within the finance sector.

Digitalization has been one of the important drivers of this transformation. The widespread integration of digital technologies into financial services development and delivery processes has significantly reshaped the traditional revenue streams by both enhancing the efficiency of existing service delivery and creating new revenue opportunities. Technological advances, including the proliferation of online and mobile banking platforms, ATMs, digital payment systems, and credit-scoring algorithms, have allowed banks to deliver traditional services more cost-effectively, improve customer experiences, and simultaneously increase fee-generating opportunities from these conventional services (Gaspar et al., 2003).

The example illustrating this phenomenon would be the radical change of the banking payment systems that have long been the principal source of fee income. Online systems and mobile terminals enable banks to attract customers who are willing to pay more for greater convenience and accessibility, especially in products like electronic bill payments, real-time fund transfers, and instant balance inquiries (DeYoung & Rice, 2004).

These advances, however, pose strategic challenges to traditional banking institutions as well. With current advances in digital capabilities, larger institutions and new market entrants are now in the position to replicate customer experiences using data analytics, artificial intelligence, and digital communication tools. As a result, digitalization might have both positive and negative impact. On the one hand, digital solutions drive the new revenue opportunities through improvements in efficiency and innovative fee income services. However, it also suggests the heightening competitive pressures from the largest institutions with high digitalization capacity,

leading to the dilution of the relationship-driven strengths traditionally responsible for the revenue base of the smaller banking groups. Understanding the shift in the relationship between digitalization and traditional revenue strategies is therefore important for the strategies of banks as they rethink, as well as to regulatory institutions as they examine the broader implications for the stability of the banking industry and for consumers (Windasari et al., 2022, González et al., 2022).

Alongside the internal redefinition of revenue flows triggered by digital transformation, the banking sector is increasingly faced with pressures from fintech and technology-driven entrants in the external environment. Typically characterized by greater agility and lower cost bases, this group of the competitors tends to target core bank functions like payment, lending, transfer of money, and management of investments. By fragmenting the traditional banking value chain and offering lean digital solutions, FinTechs and BigTech companies are reducing the exclusivity inherent in banking operations.

This competitive environment poses a serious risk to banks' interest income and fee-based revenue pools, most of all in payment and retail lending segments, where FinTechs have already gained significant market share. Increased use of digital-first finance offerings applies downward pressure to banks' profit margins and makes it harder for banks to sustain historical levels of profitability. As such, while digitalization is expected to improve efficiency within banks, its net impact on profitability is clouded, most of all in the context of growing technological rivalry inducing margin compression and forcing banks to re-examine business models actively.

## 2. Digitalization Impact on the Banking Business

Existing literature often focuses on individual aspects of digitalization, although the multifaceted impact of digitalization components on banks' profitability and business models is often considered throughout the literature. However, causal inference remains challenging, mostly due to data constraints and the complexity of separating the impacts of digitalization from other macroeconomic and institutional factors.

The development of digitalization in banking has been studied from multiple analytical angles, exposing the complex and multifaceted character of technological innovation in financial services. The definitions of digitalization in banking given by the researchers can be broadly grouped into those that focus on the fundamental transformation of business models encompassing significant strategic and organizational changes (Nguyen et al., 2023, Shanti et al., 2022, Dudin et al., 2021, Artemenko & Zenchenko, 2021, Yang & Masron, 2023), those that emphasize the aspect of adoption of digital technologies and channels that improve customer experience and efficiency (Windasari et al., 2022, Shaikh & Karjaluoto, 2015, Ciciretti et al., 2008, Dootson et al., 2016),

and those with the foundational view of digitalization as a process of converting information (Harchekar, 2018). These perspectives are interconnected. Leveraging digital channels and tools tends to bring about significant transformation in banks, which alter the way value is developed and delivered.

A substantial part of literature approaches digitalization through the lens of technological adoption, emphasizing the complete migration from branch-based service provision to internet and mobile banking, as well as the rise of digital-only or virtual banks (Di Febo & Angelini, 2019). Following this approach digital banking has become an essentially relevant topic for the policymakers in both developed and emerging economies. Some governments such as Indonesia and Hong Kong define digital-only institutions as those delivering services predominantly through electronic channels without physical branches and create the specific guidelines for the emerging industry (Windasari et al., 2022). Apart from the policy improvements, the researchers also state that the transition to the digital channels has also been linked to improvements in cost efficiency and scalability. For instance, the research on ASEAN-5 countries indicates that the use of digital infrastructure correlates positively with profitability metrics like ROA and NIM (Malik et al., 2020).

Digitalization is regarded as a significant transformation where the business models are altered to make better use of digital tools. This way, technologies such as cloud computing, artificial intelligence, and big data analytics are not only enhancements for routine operations, but they also enable businesses to think strategically and keep themselves customer-centric. The interaction models between financial entities and customers shift from being two-sided buyer-seller interaction to the multi-sided models involving network externalities thanks to the innovations (Carbó-Valverde, 2017, Lee et al., 2021). As observed in the context of European and emerging market neobanks, the shift towards digital business models has allowed financial institutions to streamline operations, enter underserved markets, and personalize offerings while achieving higher efficiency and agility (Shanti et al., 2024).

Customer experience aspect of the digitalization process also remains significant for the researchers. From this perspective the process is analyzed as means to offer faster, more convenient, and personalized banking services. The strong focus on usability, real-time access and intuitive interfaces indicates the shift in consumer expectations, particularly among younger and more digitally-native customer segments (Windasari et al., 2022). Empirical evidence also confirms that digital banking services offering enhanced convenience and user-centric features are more likely to be adopted, especially when rewards and ease of use are reinforced. At a more comprehensive level, digital transformation is defined as a strategic and organizational imperative

encompassing shifts in corporate culture, governance structures, and operational routines to leverage digital technology's benefits fully (Kane et al., 2019; Westerman, 2017). This interpretation underscores that suggests that digital transformation requires more than infrastructure investment. Organizational adaptability and leadership commitment supposedly also play an important role.

Finally, at the core of all these topics is the central concept of digitalization, which is transforming information into digital formats. It makes the data processable, storable, and transmittable, which is required for emerging concepts such as online banking and algorithmic credit scoring. Literature portrays digitalization in banking as a multifaceted and multidimensional phenomenon, driven by a combination of technological, strategic, experiential, and infrastructural forces, all of which interact to redefine the modern banking environment (Dudin et al., 2021; Harchekar, 2018).

The constantly changing nature of digitalization presents another measurement challenge. With digital tools and strategies changing so rapidly, the commonly accepted point-in-time metrics fail to present an accurate picture. Long-term data would be preferable, but it is either unavailable or only captured occasionally for the specific research or reports. Separating digital adoption from digital transformation might also be problematic. Some banking entities might adopt mobile apps and online promotion channels, but still lean towards the traditional forms of providing the financial services, which limits the transformative impact of their digital investments.

Quantifying digitalization in the banking sector also remains challenging, and most researchers have noted the difficulties of measuring this complex phenomenon. The data divergence makes cross-study and cross-country comparisons complicated and may result in contradictory findings for different regions. Even if the scope of the analysis aligns, the choice of proxies and the structure of the data itself may vary depending on the purpose of the research. Indicators like internet banking usage might mix customer preference with institutional strategy, while IT expenditure data may not reflect return on investment or transformation success afterwards (Beccalli, 2007).

The alternative methodologies such as keyword-based indices depend heavily on the assumption that disclosure reflects action, which a problematic premise in contexts where reporting standards vary or where institutions strategically manage public perceptions (Yang & Masron, 2023). This underscores the need for combination of qualitative assessments with financial metrics and usage data to derive a more comprehensive picture of digital advancement.

The issue of the measurement complexity in the research papers is approached in a variety of ways across the literature, reflecting the methodological challenges in capturing it and its multidimensional nature accurately. Since digitalization involves employing new technologies and making large-scale changes in systems and the manner of doing things, it requires various means of measurement of progress. The existing research indicates numerous approaches, ranging from basic statistics regarding technology utilisation to more expansive concepts such as measuring digital growth and economic transformation.

A common method is observing how individuals utilize digital services and technology. It may be quantifiable by estimating the number of internet bank users, the number of mobile bank users, the number of ATMs, and the number of electronic or mobile payments. The research on ASEAN-5 countries applies the number of internet banking users per institution to assess the level of digital banking implementation (Malik et al., 2020). Another research conducted in Azerbaijan indicates that 27 out of 30 banks provided internet banking, and 25 offered mobile banking services, emphasizing widespread digital access but not necessarily transformative integration (Abbasov et al., 2019). Although such indicators are straightforward, one may argue that they primarily reflect the front-end adoption of e-services rather than the depth of digital transformation across the institution's business model.

Another approach centers on technology-related financial investment. This encompasses such things as investment in IT, non-tangible long-term assets, and communication or software costs. It is premised on the belief that investing in technology assists with digital growth. One notable example is the use of growth in intangible fixed assets and intellectual property as a proxy for backend transformation, particularly software and core banking system upgrades (Beccalli, 2007, Giaretta & Chesini, 2018, Di Febo & Angelini, 2019). The data in these papers was normalized by total assets to ensure comparability across banks with different sizes and business activity types. However, while these financial indicators offer a more internal view of transformation, they may be affected by other non-digital factors and misreporting issues. Thus, they do not necessarily reveal how effectively the technologies are integrated or utilized.

Other studies apply a complex approach, evaluating bank’s digital maturity based on frameworks or models that assess the degree to which digital technologies are implemented across core operations and deriving some generalized index. Some of such country-specific indexes, such as the Vietnam ICT Index, offer a direct estimate depending on the preparedness of the infrastructure, the capabilities of the people, IT usage, and the provision of services (Nguyen et al., 2023). Such indexes consider various aspects for better insight but are difficult to compare across countries or firms due to varying assumptions, methodologies and the availability of data.

Another methodology involves the creation of Digital Transformation Indices based on various analytical and text mining techniques, therefore allowing for constructing indices of digital technology based on text data. The keywords related to digital transformation are identified and analyzed in annual reports, regulatory disclosures, or sustainability statements. The assumption is that the more a bank discusses digital-related themes, the more likely it is engaged in substantive digital transformation. (Yang & Masron, 2023). While this method has the ability to identify subtle evidence of strategic intent, it is not free from a certain level of subjectivity in the choice of keywords and relies extensively on the reporting culture and transparency within the concerned institutions. Moreover, banks may engage in rhetorical signaling without undertaking material transformation, particularly in jurisdictions with lower disclosure requirements.

The studies covering the specific digital technologies used in banking, such as artificial intelligence, cloud computing, blockchain, or biometric authentication rely on building the specific quantitative models (Bastari et al., 2020). Despite its focus on technology, this strategy threatens to overlook organizational and strategic changes that accompany full digital transformation.

Literature describes numerous approaches to measuring digitalization in banking, each based on its own specific facet while facing major limitations. Adoption-based metrics are accessible but shallow, while financial indicators offer internal depth but lack context, and index-based measures suggest strategic engagement but risk misinterpretation. The absence of a unified framework requires an integrative, multi-method approach that captures both the scale and substance of digital transformation within the banking sector in the face of fast-paced evolution of digital technologies.

# V. Empirical Data and Analysis Methodology

This study has the aim to apply a quantitative panel data framework to investigate the impact of digitalization on profitability and cost efficiency of the EU's banking industry. The analysis is carried out by employing annual macroeconomic data on the banking sector and for the 27 EU countries for the period between 2014 and 2023. As there are limitations to available data, the primary analysis is limited to the period between 2018 and 2023, a period over which comprehensive indicators of digitalization, as measured by the Digital Economy and Society Index (DESI), were consistently available for EU countries.

The main dependent variables capture the financial performance and the overall business model orientation in the banking industry in different EU countries, while the main independent variables cover the complex features related to digitalization. To control for macroeconomic variations and institutional context shifts, the models include relevant economic and structural

controls. The empirical methodology of the research relies on fixed-effects estimation to deal with unobserved heterogeneity across and within countries over time. Stringent robustness tests, such as sub-sample analyses and alternative specification tests, are conducted to enable the assessment of the validity of the results.

## 1. Data and Descriptive Statistics

The data consist of annual observations between 2014 and 2023 for the 27 member states of the European Union. However, due to limited historical availability of key indicators related to digitalization, especially those calculated from the Digital Economy and Society Index (DESI) and related Eurostat data, the main estimation sample focuses on the period 2018 to 2023. DESI Index Dataset comprises of various digital economy-related indicators, which may be used to compare and to rank European countries on a similar scale (see Appendix 1).

Due to the lack of data on digital economy indicators, although 270 observations are initially included, the balanced panel after excluding the missing values has 152 country-year observations suitable for model estimation. The data used for model estimations are drawn from publicly available and reliable databases, such as Eurostat, the Digital Economy and Society Index (DESI), and the European Central Bank (ECB).

The dataset comprises of the variables falling into the following groups:

1) Dependent Variables:

Table 1. Dependent Variables Summary Statistics

| Variable | Obs. | Mean | St. Dev. | Median | Min | Max |
|---|---|---|---|---|---|---|
| ROE | 270 | 6.68 | 6.79 | 7.18 | -31.15 | 21.9 |
| CIR | 270 | 56.74 | 9.44 | 56.42 | 30.56 | 82.79 |

Which include:

- Return on Equity (ROE) indicates the overall profitability of the banking sector;
- Cost-to-Income Ratio (CIR) reflecting how efficiently the banking sector manages to earn profits in relation to its operating expenses.

2) Independent Variables of interest (Digitalization Components):

Table 2. Digitalization Proxies (Independent Variables) Statistics

| Variable | Obs. | Mean | St. Dev. | Median | Min | Max |
|---|---|---|---|---|---|---|
| Internet Banking | 269 | 56.58 | 22.78 | 57.67 | 4.16 | 96.22 |
| High Digital Skills | 243 | 29.85 | 10.67 | 29.69 | 7.73 | 55.89 |
| Internet Usage | 188 | 85.49 | 8.11 | 86.84 | 60.78 | 98.92 |
| ICT Share | 271 | 3.86 | 1.87 | 3.9 | 0 | 8.7 |
| Ecommerce Turnover | 256 | 16.76 | 7.77 | 16.34 | 1.71 | 43.95 |

Which cover respectively:

- The proportion of people using online banking services.
- Above-basic digital skills (% of population);
- IT specialists (share of the total workforce);
- Percentage of people who use the internet regularly.
- Business e-commerce turnover (% of SME turnover from online sales).

3) Control Variables (Macroeconomic parameters)

Table 3. Macroeconomic Control Variable Statistics

| Variable | Obs. | Mean | St. Dev. | Median | Min | Max |
|---|---|---|---|---|---|---|
| GDP per Capita | 270 | 31.67 | 21.37 | 25.12 | 6.08 | 118.77 |
| Inflation | 270 | 2.75 | 4.01 | 1.55 | -2.5 | 25 |
| Interest Rate | 270 | 0.76 | 2.02 | -0.13 | -0.61 | 16.45 |
| CET1 | 270 | 16.87 | 2.9 | 16.76 | 10.23 | 28 |
| NPL | 270 | 7.38 | 8.72 | 4.06 | 0 | 50.5 |
| Education | 271 | 27.11 | 11.63 | 29.4 | 0 | 46.6 |

Which cover:

- GDP per capita (in thousand EUR);
- Inflation rate (annual % change in HICP);
- Short-term interbank lending rates (3-month interbank rate);
- CET1 Capital Ratio (stability and solvency of the banking sector);
- NPL ratio of total loans outstanding;
- Share of the population who accomplished tertiary education in a country.

For the purposes of building a comprehensive econometric model, the indicators showing similar societal tendencies and having a strong intercorrelation (see Table 4) were grouped into a single Digitalization Index. Because of the complexity involved in capturing digitalization's multidimensional nature, a finer-grained approach was taken to create the population-oriented Digitalization Index based on 3 highly intercorrelated indicators (namely Internet Banking, High Digital Skills and Internet Usage). Since other factors (ICT Share and E-commerce turnover share) indicate supply-side and digital business activity tendencies, it makes more economic sense to combine only the selected 3 indicators into the composite index reflecting the adoption of the digital tools by the population.

Table 4. Paired correlations of digitalization proxies

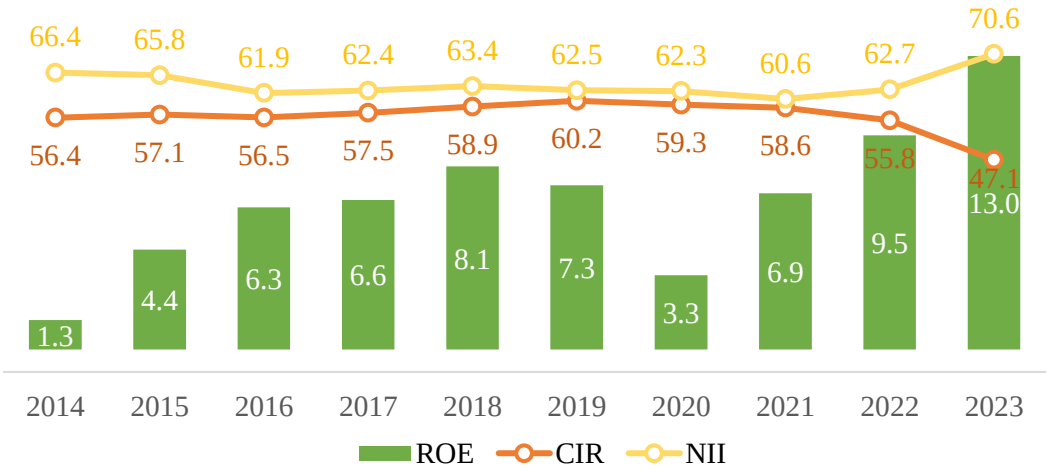
| | *Internet Banking* | *High Digital Skills* | *Internet Usage* | *ICT Share* | *Ecommerce Turnover* |
|---|---|---|---|---|---|
| *Internet Banking* | 1.00 | | | | |
| *High Digital Skills* | 0.75 | 1.00 | | | |
| *Internet Usage* | 0.85 | 0.62 | 1.00 | | |
| *ICT Share* | 0.75 | 0.63 | 0.74 | 1.00 | |
| *Ecommerce Turnover* | 0.49 | 0.39 | 0.43 | 0.51 | 1.00 |

Due to both theoretical and empirical rationales the weight of the factors was selected non-equally. As a variable directly related to the banking sector, Internet Banking Adoption factor is given the greater emphasis. Given that this indicator directly reflects digital consumer behavior central to the banking industry transformation, it received a 0.5 weight in the composite index. The supporting infrastructure digital skills indicators – Above average Digital Skills and Regular Internet Usage – each received a lower but still meaningful weight of 0.25 in consideration of their ability to provide a base for the adoption of digital financial services. The variables IT Professionals in Workforce Share and Business E-commerce Turnover represent conceptually distinct dimensions, reflecting human capital specialization and business sector digitization, respectively. Therefore, the variables were retained as independent regressors and considered separately to be able to address their respective and theoretical distinct impacts on banks' business models and performance.

It can be noticed that the pairwise correlations among the indicators that were included in the overall Digitalization Index average at approximately .74, with a peak correlation of .85 (between Internet Banking Adoption and Regular Internet Use). Moreover, all variables demonstrate high internal consistency, and notably economic meaning in the context of the research, which was verified with a Cronbach's alpha value at approximately .895 indicating excellent reliability and internal consistency, and were able to generate a composite index to alleviate multicollinearity issues, and facilitate including all variables. This weighted approach offers greater analytical precision and theoretical clarity, accurately emphasizing digital consumer engagement in the examined countries.

In order to provide a general context for the subsequent panel analysis, Figure 1 plots the development of key banking sector metrics based on the averages from observations from the gathered dataset for the European Union from 2014 to 2023: Return on Equity (ROE), Cost-to-Income Ratio (CTI), and the proportion of Net Interest Income (NII) in total bank revenues.

Figure 1. Operational Efficiency Measures' Dynamics Overview (%, 2014-2023)



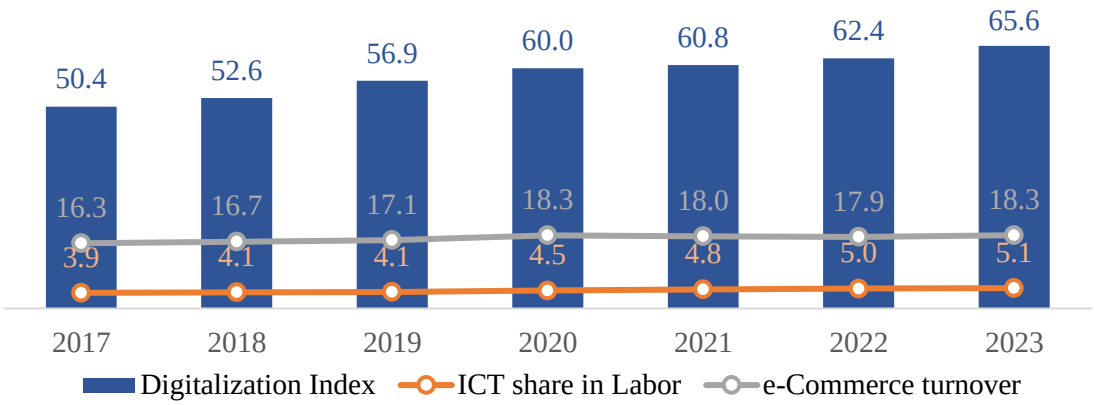

The ROE sequence has a clear cyclical pattern. Starting from a low of 1.3% in 2014 and reflecting the lingering effect of the Eurozone crisis, the profitability gradually improved to a local peak of 8.1% in 2018. The COVID-19 pandemic in 2020 caused an abrupt decline to 3.3%, consistent with global financial dislocations and increased provisioning. In the subsequent years the industry faced the substantial recovery, touching a peak post-pandemic rate of 13.0% in 2023. This trend reflects the cyclical weakness of the industry alongside its capacity to revive under favorable macroeconomic circumstances.

The CIR ratio, a reverse proxy for efficiency, remained largely consistent between 2014 and 2021, ranging between 56% and 60%. Nevertheless, from 2023, it fell drastically to 47.1%. This fall indicates a significant improvement in cost efficiency, which is most probably driven by the rapid take-up of digital technology, cost re-engineering initiatives, and enhanced scale efficiencies. The sharp post-pandemic drop in CTI is consistent with the rising ROE, corroborating the view that improved efficiency has been one of the important channels for profitability recovery.

The proportion of Net Interest Income (NII) surged to cross over 70.5% in 2023 after a gradual decline between 2014 and 2021 (from 66.4% to 60.6%). The steep increase may indicate that banks are making loans more as interest increased following the energy crisis in 2022. Supposedly, the banks are returning to the core banking business.

Cumulatively, these trends indicate that the banking industry in the European Union has transformed significantly over the past decade. In parallel, digitalization indicators from 2017 to 2023 show a consistent upward trend (see Figure 2).

Figure 2. Digitalization Proxies Dynamics Overview (2017-2023)




The Digitalization Index and ICT labor force share both increased steadily and significantly over the last years, while e-commerce turnover rose modestly after the pandemic. These trends support the premise that EU banking operates in an increasingly digital and technology-competent environment, aligning with the regression findings where internal digital capacity (ICT share) proved more influential than population-level digital use alone.

## 2. Model Overview

The analysis covers a balanced dataset of 27 European Union member states over the period from 2018 to 2023, employing fixed-effects estimation techniques to account for unobserved heterogeneity across countries. This includes unobservable country-specific factors that remain constant over time and could otherwise bias the estimates, such as legal system structure, historical financial sector orientation, or cultural attitudes toward technology adoption. The empirical approach focuses on evaluating the effect of digitalization on two focal aspects of the banking sector, namely, profitability and operational efficiency. These aspects are proxied, respectively by Return on Equity (ROE) of the banking sector and Cost-to-Income Ratio (CIR). The model accordingly treats variables as dependent in fixed-effects regressions.

The research focuses on the impact of the key digitalization proxies on the described dependent variables. The described above Population-oriented Digitalization Index that has been designed solely for use in this thesis encapsulates indicators reflecting the societal and household adoption of digital banking and technological tools. To supplement the composite index and cover further dimensions of technological infrastructure, two further digitalization-related variables are included as major regressors: the share of ICT specialists in the labor force and the share of turnover attributable to e-commerce activity in total revenues of the enterprises within the country. The selected variables represent the capacity of digital human resources in the economy (ICT_Share), the level of engagement between the business sector and the digital economy

(ecommerce_turnover). Both supposedly might influence the ability of the banking sector to capitalize on digital transformation.

One of the most important concerns in the empirical literature on the analyzed topic relates to the endogeneity, assuming that digitalization is expected to enhance banking performance, yet it is also possible that causality runs in the opposite direction. It is likely that the more profitable or efficient banks possess more resources, thus making them better able to invest in digital transformation efforts, including employing ICT experts, developing technological infrastructure, and restructuring service delivery channels. This situation creates the cyclic interconnection and the feedback loop, where improved performance drives digitalization, which, in turn, affects performance, making causal inference more challenging and possibly leading to upward-biased estimates if not controlled for.

Additionally, digitalization decisions can be driven by underlying unobservable institutional factors, such as the internal strategic focus, quality of management, innovation culture or regulatory responsiveness, which affect the efficiency indicators and profitability independently as well. While being difficult to measure, these unobserved characteristics, if not being controlled for, are included in the error term and might cause correlation between the digitalization indicators and the error, leading to endogeneity through omitted variable bias. However, since the analysis focuses on the aggregated country-level data on the banking sector these unobserved factors may largely be absorbed by fixed effects and averaged out, thus making the reverse causality the key issue potentially causing endogeneity.

In order to account for the potential endogeneity, the estimation approach was adjusted to include lagged explanatory variables, particularly the ones related to digitalization indicators and interest rates. This adjustment is supported by the temporal dynamics inherent in the process of digital transformation and the delayed impact of the interest rates on the performance of the financial entities. Investment in digital infrastructure improvement, the expansion of ICT-skilled human capital, and societal adoption of digital banking tools are unlikely to have instantaneous impacts on bank profitability or cost efficiency. Instead, such effects typically materialize gradually over time, after periods of implementation, adaptation, and organizational absorption. Consequently, since changes in digitalization indicators are expected to influence bank performance only after some period, using lags better aligns with economic theory while at the same time lowering the chances of current bank performance having any impact on such attribution factors.

Introducing a one-period lag for the key independent variables creates a clearer temporal distinction between causality and effect, minimizing the prospect of reverse causality, in case of which more profitable banks might have a larger capability to invest resources in digital infrastructure. This lag specification demonstrates the influence of past values on the present-day results of the banks, which also reduces the likelihood of the reverse causality from the current period's efficiency on the digitalization choices. This approach goes in line with previous studies, where lagged variables were implemented as a solution for simultaneity concerns in evaluating IT improvement effects on the banking industry (Shin, 2001). Including not only the lagged digitalization parameters, but also both the past and the current interest rate enhances the understanding of the direct and lagged effects of monetary policy on the performance of the banks, given the way the revenue and costs adjust to the policy changes over time. The specification contributes to the credibility and robustness of the results, as the cause-and-effect relationships in the results are clearer.

Although this approach cannot completely eliminate the problem of endogeneity arising from the omitted variables, it increases the strength of the causality inferences and follows the principle of sequential exogeneity, holding that previous period values have dynamic effects but are not affected retrospectively by the current levels of the profitability and operational efficiency. This approach is also used in the relevant literature in the absence of relevant instrumental variables and provides a temporally stronger estimation model, similar to other empirical research in the context of banking IT technology and operational performance. The introduction of lagged variables assumes a one-way effect of the previous conditions on the current performance results, avoiding the simultaneity bias of the estimations (Shin, 2001, Beccalli, 2007).

From an econometric standpoint, this approach overcomes endogeneity problems caused by simultaneity and reverse causality by assuming the lagged variables are absolutely exogenous and uncorrelated with the error term of the current period while accounting for fixed effects and certain covariates. Therefore, the model improves the credibility of causal conclusions, brings about enhanced explanatory power and signifies more theoretically consistent patterns for coefficients, which is proven by the identified strong lagged effect of interest rates and the labor composition of ICT on the profit margin, as well as the promotion of cost efficiency. Although the applied method cannot rule out all existing types of endogeneity due to omitted variable bias as well as measurement error, it addresses the most relevant issue for the purposes of this research by making it unlikely for current bank profitability, income diversification, or efficiency ratios to have any impact on past levels of digitalization in society and companies.

In addition to the digitalization variables, the model controls for a number of country-specific structural and/or macroeconomic factors which are expected to influence bank performance, including GDP per capita as a proxy for economic development, inflation and short-term interest rates to capture broader macro-financial conditions, capital adequacy of the banking sector (using CET1 ratio), the share of non-performing loans as a measure credit risk, and an education measure of shares of tertiary graduates within the population. Year fixed effects were also included to account for EU-wide shocks (such as regulation changes) or any systemic shock in place of the impact of the COVID-19 pandemic.

The general model specification can be expressed as follows:

$$Y_{it} = \alpha + \beta_1 \text{Digitalization}_{it-1} + \beta_2 \text{ICT}_{it-1} + \beta_3 \text{Ecommerce}_{it-1} + \gamma \text{X}_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Where:

- $Y_{it}$ is the dependent variable (e.g., ROE, CIR) for country *i* in year *t*,
- $\text{Digitali}zation_{it-1}, \text{ICT}_{it-1}, \text{Ecommerce}_{it-1}$ denote the lagged digitalization indicators,
- $\text{X}_{it}$ represents the other macroeconomic control variables vector,
- $\mu_i$ captures unobserved country-specific effects,
- $\lambda_t$ accounts for time-specific effects (e.g., EU-wide shocks),
- $\epsilon_{it}$ is the error term.

This model setup allows for a nuanced estimation of how various dimensions of digital transformation affect the evolving performance and business model orientation of banks across the European Union. Alternative specifications, including various model specifications, lagged digitalization variables and interactions with macroeconomic conditions, will be tested to assess the robustness and causal plausibility of the results. Where appropriate, heteroskedasticity- and autocorrelation-consistent standard errors will be used.

## 3. Statistical Tests

To obtain statistically robust empirical models and assess the adequacy of inference, a range of post-estimation diagnostic tests for both models was performed, focusing upon addressing key econometric issues that arise in panel data contexts such as: heteroskedasticity, serial correlation, multicollinearity, cross-sectional dependence, and the appropriate fixed or random effects model specification.

The first step of the analysis included checking for multicollinearity using the Variance Inflation Factor (VIF). Assessing multicollinearity using VIF, the regressors appear sufficiently independent (Table 5). Across both models the values for the VIF remained far below the typically accepted threshold of 5. In this analysis, the Digitalization Index and percentage of ICT specialists in the labor force were observed to have VIF values slightly higher than others (roughly 3.4 and 3.8). However, the moderate correlations among digitalization variables do not approach levels that would threaten the accuracy of the regression estimates or inflate standard errors. Thus, the multicollinearity is not considered a significant concern.

Table 5: Variance Inflation Factor (VIF) Results

| **Variable** | **VIF** |
|---|---|
| Digitalization Index | 3.41 |
| ICT | 3.85 |
| Ecommerce Business Turnover | 1.66 |
| GDP per Capita (thsd EUR/USD) | 2.66 |
| Inflation | 1.57 |
| Interest Rate | 1.90 |
| Bank Assets (bln) | 1.58 |
| Common Equity Tier 1 (CET1) | 1.50 |
| Non-Performing Loans (NPL) | 1.91 |
| Education | 2.40 |

The selection of a fixed-effects model specification was justified by the Hausman test, which reveals systematic differences between the fixed and random effects estimators, suggesting that country-specific diversities - such as the structural features of each national banking system, the maturity of the country's digital landscape, or the regulatory disposition - are likely correlated with the explanatory variables. In both ROE and CIR models the test decisively favored the fixed-effects specification $\chi^2 = 23.74$ and 16.95, $p < 0.001$ and 0.009 respectively. Hence, given the theoretical rationale and the structure of the data, the fixed-effects estimator was retained for both models to ensure consistency and comparability of results.

Heteroskedasticity was assessed by means of the Breusch-Pagan test, which shows that in the ROE model, the null hypothesis of homoskedasticity could not be rejected at the 5% level ($p = 0.0736$), while CIR model produced statistically significant test results ($p < 0.001$), suggesting heteroskedasticity existed. To address this issue, all reported coefficients and significance levels used heteroskedasticity-consistent robust standard errors (HC1) in both models. The result illustrates that the variance of the residuals does not stay consistent across units and thus violates the classical linear model assumption. In order to account for this, all standard errors reported in what follows were calculated using heteroskedasticity-consistent estimators (type HC1), permitting valid inference in the presence of non-constant error variance.

For cross-sectional dependence, the Pesaran CD test identified a significant contemporaneous correlation between countries in the ROE model only ($z = 4.61$, $p < 3.98e\text{-}06$). The substantial correlation is likely attributable to the interdependence of European banking sectors in terms of profitability and consequently contribute to EU-wide policy diffusion. However, there was no significant correlation found in the CIR models, with this suggesting that the residuals were the most independent across countries in these specifications. This pattern highlights that the profitability measures may be more susceptible to common regional influences than operational measures.

Additional diagnostic tests revealed that there is serial correlation in the panels, where this was confirmed by the Wooldridge/Breusch-Godfrey test for autocorrelation. The diagnostic test showed first-order serial correlation in the ROE model (p-value = 0.02184). This finding is expected for macro-panel data, where it is common to find time-persistent effects and autocorrelated shocks. The use of cluster-robust standard errors at the country level helps reduce the extent of these issues on inference.

Collectively, these diagnostic tests reaffirm the suitability of fixed effects panel regression model and the validity of the corrected standard errors- to accommodate heteroskedasticity and serial correlation. Econometric reliability and contextual relevance of the estimation results in the following section may thus be interpreted with confidence.

## 4. Alternative Estimations

In order to test the robustness of the findings of the fixed-effects panel model results, the variety of alternative estimation methods were examined. These alternatives included combinational pooled panel data OLS and an instrumental variables (IV) model, in which the initial tests were run in order to assess for potential endogeneity between operational efficiency and profitability.

For the purpose of establishing a baseline comparison, the pooled OLS regression model was constructed using the same specifications as the fixed-effects models. The pooled OLS estimator differs from the fixed-effects estimator in that the fixed-effects estimator does not assume that any country-specific unobserved effect represents a fixed effect influencing the dependent variable. The models have robust standard errors to address the effects of heteroscedasticity, which is relevant in a dataset with a cross-sectional dimension. Several preliminary comparisons indicate while the coefficients' signs and overall patterns are fairly similar, some of the estimated effects can be exaggerated in OLS as it does not control for omitted unobserved heterogeneity.

Due to that the constructed OLS models fail to capture the effects of the digitalization parameters on the dependent variables. Despite still being statistically significant overall, the application of the pooled OLS regression model is less appropriate in contexts where unobserved heterogeneity exists across cross-sectional units, including national regulatory environments, institutional legacy effects, or technological readiness. The more restrictive assumptions embedded in the OLS framework limit its usefulness to a supportive diagnostic function in this research (see Appendix 2).

An instrumental variable (IV) estimation method, based on two-stage least squares (2SLS), was considered as one of the possible ways to address the issue of endogeneity, especially for the association between bank profitability and efficiency improvements resulting from digitalization. Ideally, a suitable exogenous instrument such as the timing of nationwide digital policies across the country, European structural funds allocations towards the development of digital infrastructure, or the past rollout of relevant policy changes would be used to isolate variation in digitalization unrelated to current bank performance. However, the unavailability of regular country-level data for such broad instruments across the used panel and time horizon made it impossible to develop a valid and powerful instrument that can address both relevance and exogeneity testing requirements.

Among the available data, the most suitable candidate to be considered as an instrument was Digitalization Index and its proxy the e-commerce turnover share of the enterprises. In the context of this research, e-commerce turnover share might be identified as an external measure of the strength of digital adoption, assumingly unaffected by the internal banking entities' policies affecting digital banking adoption. This assumption was based on the fact that acceptance of the e-commerce form of the business within the country might affect the overall digitalization index within the country, but not the operational efficiency of the banking industry directly.

Despite the intuitive theoretical appeal, the IV estimation employing e-commerce turnover share as an instrument predicting the Digitalization Index yields statistically insignificant results and fails to capture the effects of both digitalization and macroeconomic parameters. The estimates produced large standard errors and statistically insignificant results, meaning that the estimates were unstable. These issues indicate that there is likely a violation of the relevance condition for instrumental validity, for instance, that E-commerce turnover share does not have enough power to determine Digitalization Index in this case. Therefore, the IV approach was not pursued further, and the findings of the models are not included in the main analysis part of the thesis and are documented for completeness purposes (see Appendix 3).

Consequently, the analysis proceeded with fixed-effects regressions that offered clearer, statistically robust insights. Although other models could provide good checks on the robustness of the main specifications, the fixed effects model is still the theoretical and statistically appropriate estimator for this research. It controls for unobserved, time-invariant heterogeneity and produces consistent estimates under weaker assumptions than pooled OLS or IV.

# VI. Estimation Results

The two panel regression models under examination in this research, namely the models predicting return on equity (ROE) and cost-to-income ratio (CIR), are statistically significant at the 1% level by their respective F-tests. This suggests that the group of independent variables included in each model collectively and meaningfully accounts for variation in the dependent variable. The explanatory capability of the models, as measured by $R^2$, ranges at 38% and 51% respectively (with Adjusted $R^2$ being at 18% and 36%), which suggests a high degree of fit considering the macro-financial and cross-national character of the data.

The Return on Equity (ROE) model (see Table 6 and Appendix 4), which combines digitalization drivers from past years with current and lagged interest rates, examines factors that affect the profitability of banks in the European Union.

Among the digitalization variables, the lagged ratio of ICT professionals in the labor force reveals the strongest statistically significant and positive relationship with ROE ($p = 0.002$). This result indicates that banks need employees who possess technological competence in order to be more profitable and to provide information-intensive and scalable financial services.

The Digitalization Index, which is meant to capture societal uptake of digital banking services and is lagged by one year to control for possible delayed reactions, exhibits a positive correlation with Return on Equity (ROE) and is close to statistical significance at a 10% level ($p = 0.087$). While not strongly confirming the profitability hypothesis at conventional significance levels, the positive coefficient is in line with expected results. This suggests that increased public use of digital banking services could increasingly improve profitability; however, such effects may occur over longer time horizons or operate indirectly through other efficiency-related channels, as opposed to occurring immediately.

The introduction of lagged interest rates as a macroeconomic variable greatly improves the explanatory power of the model, showing that past interest rates have a positive and statistically significant effect on current levels of bank profitability ($p = 0.009$). The result confirms that only after some period of time can a lag in interest rates bring about beneficial effects on bank

profitability. Although current interest rates have a positive direction, they fail to reach statistical significance, hence strengthening the argument that beneficial effects of increasing interest rates accrue largely over a time lag. The education level also tends to show a negative and statistically significant relationship with profitability in the banking firm ($p = 0.012$). While this result might seem counterintuitive at first, it possibly indicates upward pressures in labor costs in areas with high education levels, thereby reducing traditional banking profit margins.

Table 6. ROE model estimation results

| **Variable** | **Coefficient** | **Robust SE** | **p-value** |
|---|---|---|---|
| Digitalization Index (t-1) | 0.119 | (0.069) | 0.087 |
| ICT (t-1) | 4.520 | (1.459) | 0.002 ** |
| Ecommerce Turnover (t-1) | -0.062 | (0.183) | 0.736 |
| Interest Rate (%) | 0.260 | (0.256) | 0.312 |
| Interest Rate (t-1) (%) | 0.459 | (0.174) | 0.009 ** |
| Education | -1.015 | (0.397) | 0.012 * |

Observations: 151
$R^2$: 0.3787, Adjusted $R^2$: 0.18254
F-statistic: 6.94956 on 10 and 114 DF, p-value: < 0.001

The findings from the ROE model underscore the importance of structural digital abilities as key determinants of the profitability of banking. Special attention should be given to specialized information and communications technology workforce. However, digital accuracy and digital banking sales channel might also be relevant for optimizing the revenue inflows. This conclusion goes in line with general theoretical models and earlier empirical studies (Yang & Masron, 2023, Sayari, 2024).

Within the CIR model (see Table 7 and Appendix 5), a set of factors has been found to be statistically significant determinants of operational efficiency. The lagged Digitalization Index has a significantly negative coefficient ($p = 0.010$), which indicates that higher societal acceptance of digital technology has been associated with better cost efficiency for banks. In addition, the lagged share of ICT experts has a strong negative relationship ($p = 0.017$), with it indicating that it is highly crucial to sharply reduce operational expenses. These results consistently show that digitalization, in both societal and workforce-related aspects, strongly assists in stimulating competitiveness and enhancing operations in banking.

Macroeconomic factors also have impact on the cost efficiency. The short-term interest rate is related to the CIR negatively ($p < 0.001$), implying that when interest rates are high, revenues increase more than operating expenses, resulting in improved business efficiency. On the other hand, inflation significantly increases operating costs in a way that inflationary factors add additional operating costs to banking entities, negatively impacting efficiency in total.

Table 7. CIR model estimation results

| Variable | Coefficient | Robust SE | p-value |
|---|---|---|---|
| Digitalization Index (t-1) | -0.243 | (0.093) | 0.010 * |
| ICT (t-1) | -4.602 | (1.901) | 0.017 * |
| Inflation (%) | 0.434 | (0.127) | <0.001 *** |
| Interest Rate (%) | -1.196 | (0.333) | <0.001 *** |

Observations: 152
$R^2$: 0.5105, Adjusted $R^2$: 0.3616
F-statistic: 13.3282 on 9 and 115 DF, p-value: < 0.001

Together, these large-scale empirical accounts offer strong evidence of the importance of cost efficiency as a key mechanism by which technology and macroeconomic factors impact banking performance. Notably, the strong impact of digitalization, viewed from the perspective of ICT human capital as well as societal digital engagement, serves to underscore operational transformation as central to digital banking development.

The findings show that digital transformation's impact on banking performance is significantly enhanced where focus is placed on structural and institutional digital capabilities, as opposed to a mere focus on digital interfaces for consumers. Although the Digitalization Index lacks a strong, explicit impact on profitability, its statistically significant correlation with cost efficiency highlights that societal maturity in digital engagement has real, if indirect, effects over time. By contrast, the ICT workforce repeatedly emerges as a strong driver of improved cost structures, which, in turn, helps create sustained competitive excellence in banking.

While consumer-facing innovations improve the user experience and create loyalty, their impact in terms of profitability appears to be slightly weaker in comparison to digital capacities built in-house through the workforce. Consistent gains in efficiency call for specific investments in human resources as well as structural digital readiness.

Overall, the constructed models provide complex evidence in support of the initial hypotheses. The profitability hypothesis (H1) is partially supported, most vividly evidenced by the strong positive correlation found to exist between specialization of ICT employees and profitability. While direct measures of societal digitalization show limited short-run impact upon profitability, its indirect contribution, as mediated by higher operation efficiency, can nevertheless still be evidenced. The cost efficiency hypothesis (H2) is, however, unambiguously confirmed since both digitalization of society and specialized digital human capital are found to represent key determinants of operation efficiency. These robust negative, statistically significant correlations emphasize internal, supply-side digital capacities as key determinants of banker cost efficiency, profitability, as well as long-run competitiveness.

# VII. Policy Implications

The results of this research provide useful data for financial policymakers and banks confronted with the evolving world of digital technology within the European Union. The common theme that emerges from a closer analysis is the critical role played by cost efficiency, particularly as a crucial mediating variable connecting macroeconomic conditions, digital capabilities, and profitability in banking. Improving economic performance need to place the development of operational efficiency at the core of strategic goals.

One of the most interesting findings concerns the impact of digital human capital on banking operational efficiency. More precisely, the share of ICT professionals in the labor force always demonstrates a strong correlation with improved cost efficiency as well as profitability, thereby indirectly supporting more robust and lucrative business models. This indicates that successful digital transformation in the banking context is largely driven by in-house institutional workers' capabilities, as well as by organizational resources, rather than by purely externally triggered technological take-up or shallow consumer-facing technology. Policymakers, therefore, have a strong case to encourage digitally educated professionals to develop, be hired, and be retained in the banking sector. The efforts can take different forms, such as professional training programs, public-private partnerships to upgrade skills development, or labour market regulations designed to ease bottlenecks to intra-EU mobility for digital experts.

Digital maturity of society, measured as the Digitalization Index and explaining the acceptance of digital tools and banking in particular by the public, allows for improved efficiency in operations and potential future profitability benefits for banking organizations. The conclusion reiterates that widespread digitalization of society can directly and positively impact operational performance of banks in the long run, although the effects might be harder to track in the short run. Policymakers should, therefore, increase efforts towards promoting digital literacy, closing digital divides, and facilitating digital technology adoption among a broader public. Such efforts not only increase consumer empowerment as well as broaden financial inclusion, but also create a scenario that spurs digital transformation as well as productivity gain in banks.

At macroprudential and monetary policy levels, the prominent effects of both current and lagged interest rates, as well as inflation rates, highlight the importance for central banks and regulatory authorities to cautiously consider the interaction between monetary policy and the trajectory of digitalization in the banking industry. To counteract potential complacency and to enable continued adaptation, it might prove necessary for policymakers to introduce regulation

incentives, set up supervisory expectations, or set forth explicit mandates for continued digital investments, even in cases of favorable macroeconomic context.

In summary, the evidence suggests a multifaceted policy strategy entailing the parallel enhancement of societal technological readiness among consumers and the systematic development of internal digital competencies within banks. EU-level policies, including the Digital Europe Program, and national initiatives to improve digital literacy, support the development of fintech, and enhance labor market flexibility need to be more closely aligned with the specific needs of the banking industry. Aligning these initiatives with what others want for digital expansion and what firms can realistically deliver will enhance the advantages of digitalization for the productivity, profitability, and long-term performance of European banks and help the lawmakers maximize these advantages.

# VIII. Limitations

The research considers what digitalization does to the business model of EU banks and provides valuable insights, however, certain limitations should be acknowledged.

## 1. Data Limitations

The empirical methodology of this research is constrained by data availability and reliability across different countries. The baseline estimation period is between years 2018 and 2023, where for European Union member states, standardized measures relevant to digitalization as well as the reliable and comparable data on the effectiveness of the financial sector for all the EU countries can be obtained. However, irregular reporting on different variables for different countries and years adds variability to the core dataset. Due to the lacking data the model building required about one-third of data points (mostly from the previous time periods (2013-2017)) to be discarded owing to missing values, which is likely to introduce selection bias into the sample as well as reduce the comparability between the present sample and panel data models.

In addition, some data relevant at a theoretical level, including detailed data on IT spending, bank-level or national-level strategic plans in the field of digital finance, or thorough analyses of non-interest income, were not available for all countries uniformly and were thus excluded from analysis. Finally, the analysis is conducted using national aggregate data rather than data at the firm level, which can hide unique digital approaches followed by banks and the heterogeneity of their transformation paths.

In short, although proxy measures such as the number of ICT experts, households' involvement in digitalization and business e-commerce generated revenue are informative, they

are indirect measurements of banking institution digital transformation. Therefore, it is crucial that these measures are explained cautiously and placed within context appropriately.

## 2. Model Imperfections

Apart from data constraints, several model-based imperfections arise from the methodological choices and econometric structure employed in this thesis. Fixed-effects panel data has substantial econometric implications, allowing to control for the heterogeneity, however, it also has limitations that the research cannot overcome.

First of all, fixed-effect models completely eliminate all the differences between countries, focusing primarily on changes inside of countries only. This is a really effective method for controlling the time-constant variables like legal and institutional systems and realities of banking sector as well. However, it has its own disadvantages. For instance, if some of the factors have relatively low speed of change, they might be underestimated by the model. One of the examples of the slow changes in the realm of digitalization is the rate at which countries are accepting the Internet and the fraction of users with internet banking.

Secondly, the fixed-effects estimator requires the assumption of zero correlation between the regressors and the error term. While attempts were made to address any potential endogeneity concerns (by leaving out variables known to be determined simultaneously, by employing lag structures in some exploratory models, by running an instrumental variable estimation), the risk of omitted variables and reverse causality remains. For instance, even though operational efficiency (CIR) is represented as an input into profitability (ROE), the causality may plausibly move in both directions leading to the potential for bias in the estimates. The attempted IV specification, despite being theoretically motivated, could not be well executed due to instrument weakness and statistical insignificance.

Third, the regression analysis of panel data is highly influenced by the standard error assumptions that are violated in the models. The tests that are performed in the models to test the validity of the models show that heteroscedasticity and autocorrelation are present in the data of some models, in particular in the model that explain ROE effects. The cross-sectional dependence in ROE model is significant, which might be due to the interdependency of the European banking sector. Still, it is essential to take it into consideration in order to avoid biased standard errors. Even though, in this case, the robust standard errors, which are heteroscedasticity- and autocorrelation-consistent, were applied, it would still be more appropriate to use more sophisticated techniques, such as panel-corrected standard errors, in the future research.

Finally, the fixed-effects model is structurally limited and does not account for more complex relationships that could emerge from the digitalization of the banking sector. More specifically, banks are likely to develop unique strategies, adopt varying techniques, and evolve over time at varying rates. It would be complicated to represent the full range of these interactions and capture the actual effect of these individual strategies using the aggregate average-bank model on the banking sector.

## 3. Endogeneity Concerns

Despite the methodological adjustments adopted in this research, endogeneity concerns still remain central to the validity of the estimated impacts of digitalization on the banking sector's performance. Endogeneity suggests the correlation between the explanatory variables and the error term and compromises the validity of the regression estimators. In the specific case of this study, endogeneity is most likely caused by reverse causality of the effects and the bias generated by omitted variables.

The most critical problem concerns the causal relationship between digitalization and profitability. While the theoretical assumption is that digitalization contributes to profitability through enhanced efficiency and innovation, a possibility is that more profitable banks possess superior internal resources with which to invest in digital technologies, infrastructure, and human capital. As the evidence from the existing literature suggests, financially strong banks might lead the way in the development of their own digitalization, thereby reversing the causal direction (Nguyen et al., 2023). In this case, simple regression techniques might overestimate positive digitalization effects, with coefficients that are upward biased.

The variables not taken into account within the model, such as unobserved managerial capabilities, regulatory environments, or strategic orientation of the banking sector toward technology may have positive correlations with both digitalization measures and bank performance indicators. For instance, if banks with better management practices show a capacity for faster or more successful implementation of digital solutions, their superior performance may be falsely linked to the process of digitalization alone, which would effectively overstate the digitalization effect. The nature of the banking industry and the strong incentives for more efficient institutions to actively pursue new technologies make it seem more likely that omitted-variable bias distorts upward, thus overstating the positive effects of digitalization.

The study initially attempted to use an instrumental variable (IV) approach to more effectively address the issue of endogeneity, but was faced with practical constraints. The theoretical justification of using IV derives from the argument that more profitable banks are more

likely to invest in its digital facilities and operational segments, thus creating a reciprocal relationship that biases estimates derived from fixed-effect regressions. In order to address the reverse causality issue, the reliable unaffected measures of the digitalization capacity would be required. These include structural policy shifts or historical infrastructure investments in ICT and EU innovation funds as indicators of long-term digital preparedness. Yet, these indicators tend to be sporadically available for the 27 EU countries, making IV analysis challenging. The unavailability of regular country-level data for such broad instruments across the used panel and time horizon made it impossible to develop a valid and powerful instrument that can address both relevance and exogeneity testing requirements.

In the search for a suitable instrument for a substitute solution, the share of the e-commerce business turnover was considered as a proxy for the Digitalization Index considering its interdependencies with digitalization adoption in the country and overall business efficiency. However, it failed to meet the relevancy condition in the early stages of the regression analysis. Therefore, the weak instruments emerged as a cause of a heightened probability of bias compared to the initial estimators. Thus, the IV approach was abandoned in favor of using lagged regressors, which share the need for still-strong identifying assumptions but offer a more distinct and stable solution with the constraints of the available data.

In view of the above limitations in the model, fixed-effects panel data approach is adopted, using lagged digitalization variables with macroeconomic controls. Although this approach cannot eliminate the problem of endogeneity, it increases the strength of the causality inferences by observing the principle of sequential exogeneity, which holds that previous period values have dynamic effects but are not affected by their contemporaneous shocks. This approach is also used in the relevant literature in the absence of relevant instrumental variables and provides a temporally stronger estimation model, similar to other empirical research in the context of bank technology and performance. It assumes a one-way effect of the previous conditions on the current performance results, avoiding the simultaneity bias of the estimations. The sequential model satisfies the assumption that digitalization choices realized during period t-1 will affect the profitability or productivity during period t, without the possibility of the opposite causality. Such a method is prevalent in many related studies, with the lagged independent variables used as instruments to avoid simultaneity when investigating IT investment and performance (Shin, 2001, Beccalli, 2007).

In addition to the measures of digitalization, the frameworks consider both the lagged and current interest rates as the main variables. The model recognizes that the policy shock ramifications can impact the expenditures and revenues of the banks over different periods. The

consideration of the two variables helps identify the lagged and immediate implications of interest rate fluctuations, as a way of avoiding the implications of endogeneity in the macroeconomic parameters. This approach also fully addresses the issue of the delayed effects of the monetary policy choices on the financial performance of the banking entities.

The application of the lagged explanatory variables to address endogeneity relies on the concept of sequential exogeneity, suggesting that the past explanatory variable values are not correlated with the current error term after fixed effects and other variables are controlled. Supposedly, the last year's digitalization actions, such as change of the number of ICT professionals and the extent to which people were engaging in digital activity, are believed to influence how the banks currently perform. At the same time, the current performance of the banks should not retroactively alter the explanatory variables in the past. This assumption is likely to make the model indicate cause and effect, particularly where things occur concurrently. It may, however, still be biased if there are significant time-based variables influencing digitalization trends and performance in the same manner.

Alternative approaches addressing the endogeneity issue in the literature, such as Granger causality tests in Vector Autoregressive (VAR) models or Panel Autoregressive Distributed Lag (ARDL) estimators, offer feasible alternatives to distinguishing between short- and long-run relationships between digitalization and performance (Shanti et al., 2022). However, the application of such approaches requires a more extensive dataset of time series at the individual bank level, along with stationarity tests, which was not feasible within the constraints afforded by the available dataset. Future research efforts can aim to explore these approaches with greater precision, as longer bank-level panels become available.

Overall, though the use of lagged variables enhances robustness of estimations and identification of causal relationships discovered within the model, the method does not fully solve the problem of endogeneity. The identification assumptions underpinning the model continue to be tight and are not testable. The most important of these assumptions to be proven is that the previous values of the explanatory variables should be exogenous to the current period. The results provided in the thesis should therefore be seen as correlational estimators with lower bias, rather than as firm identifications of causal effects. The ongoing research using structural models, natural experiments, or richer longitudinal panel datasets is required to properly explain the causal relationship between digitalization, macroeconomic conditions, and banking performance.

# IX. Conclusion

This thesis explored the impact of digitalization on bank sector financial performance and business models in European Union nations based on two key dimensions: profitability and operational efficiency. By analyzing panel data for 27 EU member countries spanning 2018 to 2023, fixed-effects regression methods were employed in order to account for unobserved heterogeneity specific to a country while also employing robust diagnostics and alternative estimation methods for comparison.

There were several principal findings from the empirical investigation. First, the proportion of ICT professionals in the workforce is consistently a statistically significant driver of both cost efficiency and profitability in the banking sector, suggesting that human capital availability in the digital business is essential for the realization of a successful digital transformation. The general population-wide digital adoption is directly and significantly impactful on the cost efficiency indicators, and potentially has a hidden effect on the profitability in the long run, so it should also be supported by the relevant digitalization policies. Another finding was that macroeconomic determinants, notably lagged interest rates and inflation, have powerful and long-lasting influences on the business models, thereby highlighting the necessity of coordination of digital strategy with macroeconomic risk policy.

Policy implications comply directly with these results. In a bid to foster digital competitiveness and banking resilience, policy structures should not only enable digital inclusion but also focus on digital workforce development and institutional capacity building. Policies that aim to encourage ICT specialization, global mobility of tech talent, and organizational innovation among banks can play an influential role in the contribution of digitalization to performance.

Through the convergence of empirical information, the thesis asserts that the digital transformation process in the banking industry goes beyond simple technology and actually revolves around human resources. Organizations that manage to align their digital tools with their internal human assets are poised to thrive in an increasingly dynamic financial landscape.

Future research may extend this analysis by including bank-level data, considering longer time spans, or utilizing structural models and reliable instrumental variables to more clearly identify causal channels. Nonetheless, this paper offers a comprehensive and policy-relevant conceptualization to discern the interplay between digitalization and economic and institutional frameworks in the realignment of contemporary banking practices throughout Europe.

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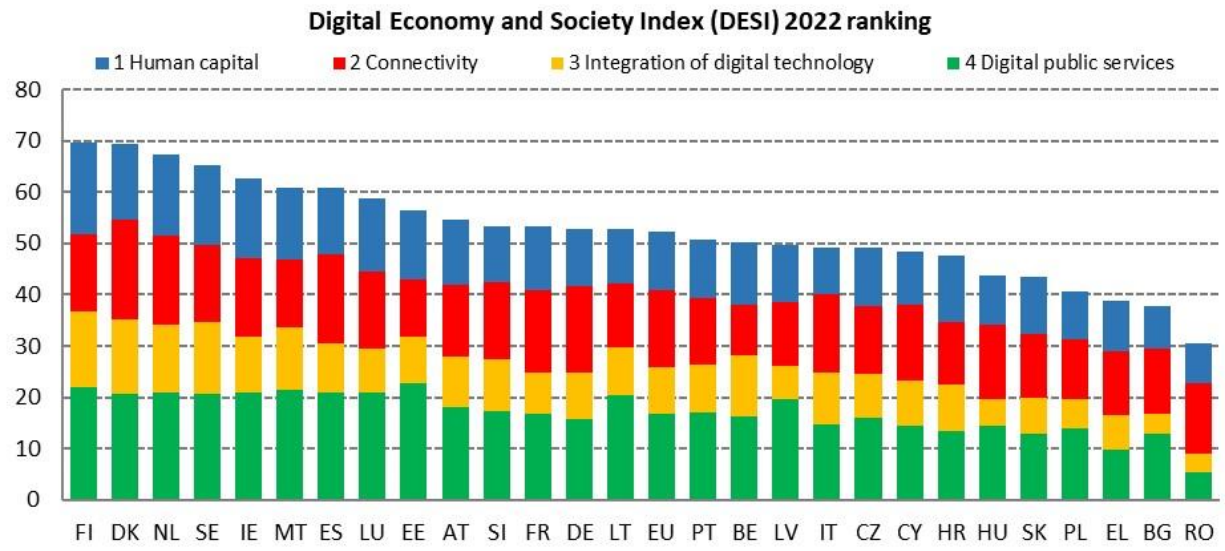
# Appendix

Appendix 1. DESI Index 2022 Components and Countries Ranking




Source: European Commission. URL: https://ec.europa.eu/commission/presscorner/detail/de/qanda_22_4561

Appendix 2. Pooled OLS Model Estimations

Output of the OLS Model for ROE

| Variable | Coefficient | Std. Error | t-value | p-value |
|---|---|---|---|---|
| Intercept | 2.706 | 3.142 | 0.861 | 0.390 |
| Digitalization Index (t-1) | -0.047 | 0.031 | -1.508 | 0.133 |
| ICT (t-1) | 0.223 | 0.491 | 0.453 | 0.651 |
| Ecommerce Turnover (t-1) | 0.034 | 0.061 | 0.570 | 0.570 |
| GDP per Capita (thsd EUR) | -0.068 | 0.024 | -2.828 | 0.005 ** |
| Inflation (%) | 0.043 | 0.116 | 0.372 | 0.710 |
| Interest Rate (%) | 0.494 | 0.284 | 1.737 | 0.084 |
| Interest Rate (t–1) (%) | 0.549 | 0.294 | 1.868 | 0.064 |
| CET1 Capital | 0.395 | 0.154 | 2.567 | 0.011 * |
| NPL | -0.481 | 0.069 | -7.007 | <0.001 *** |
| Education (% with tertiary) | 0.097 | 0.047 | 2.059 | 0.041 * |

Observations: 182 (89 observations removed due to missing values)
$R^2$: 0.445, Adjusted $R^2$: 0.413
F-statistic: 13.73 on 10 and 171 DF, p-value < 0.001

Output of the OLS Model for CIR

| Variable | Coefficient | Std. Error | t-value | p-value |
|---|---|---|---|---|
| Intercept | 64.661 | 5.122 | 12.625 | <0.001 *** |
| Digitalization Index (t-1) | 0.062 | 0.052 | 1.193 | 0.234 |
| ICT (t-1) | -1.797 | 0.794 | -2.264 | 0.025 * |
| GDP per Capita | 0.159 | 0.039 | 4.044 | <0.001 *** |
| Inflation (%) | 0.265 | 0.192 | 1.381 | 0.169 |
| Interest Rate (%) | -1.552 | 0.471 | -3.299 | 0.001 ** |
| Interest Rate (t–1) (%) | -0.674 | 0.489 | -1.377 | 0.170 |
| CET1 Capital | -0.231 | 0.255 | -0.906 | 0.366 |
| NPL | 0.003 | 0.101 | 0.028 | 0.978 |
| Education (% with tertiary) | -0.130 | 0.078 | -1.652 | 0.100 |

Observations: 187
$R^2$: 0.2836, Adjusted $R^2$: 0.2471
F-statistic: 7.783 on 9 and 177 DF, p-value < 0.001

Appendix 3. IV Approach Estimations (second-stage output)

| Variable | Coefficient | Std. Error | t-value | p-value |
|---|---|---|---|---|
| Digitalization Index (Predicted) | 0.646 | 1.316 | 0.491 | 0.624 |
| ICT (% of labor force) | 2.671 | 2.387 | 1.119 | 0.265 |
| GDP per Capita (thsd EUR) | -0.057 | 0.510 | -0.112 | 0.911 |
| Inflation (%) | 0.023 | 0.107 | 0.216 | 0.830 |
| Interest Rate (%) | 0.160 | 0.854 | 0.187 | 0.852 |
| Interest Rate (t–1) (%) | 0.410 | 0.330 | 1.243 | 0.216 |
| CET1 Capital | -0.953 | 1.924 | -0.495 | 0.621 |
| NPL | 0.251 | 1.034 | 0.243 | 0.808 |
| Education (% with tertiary) | -0.804 | 0.424 | -1.896 | 0.060† |

Observations: 156
$R^2$: 0.2962, Adjusted $R^2$: 0.1275
F-statistic: 6.826 on 9 and 146 DF, p-value: < 0.001

Appendix 4. Panel Data Regression for ROE Model (extended table)

| **Variable** | **Coefficient** | **Std. Error** | **t-value** | **p-value** |
|---|---|---|---|---|
| Digitalization Index (t-1) | 0.119 | 0.069 | 1.725 | 0.087 |
| ICT (t-1) | 4.520 | 1.459 | 3.097 | 0.002 ** |
| Ecommerce Turnover (t-1) | -0.062 | 0.183 | -0.338 | 0.736 |
| GDP per Capita | 0.138 | 0.144 | 0.958 | 0.340 |
| Inflation (%) | 0.032 | 0.096 | 0.337 | 0.737 |
| Interest Rate (%) | 0.260 | 0.256 | 1.015 | 0.312 |
| Interest Rate (t–1) (%) | 0.459 | 0.174 | 2.638 | 0.009 ** |
| CET1 Capital | -0.356 | 0.296 | -1.202 | 0.232 |
| NPL | -0.132 | 0.114 | -1.150 | 0.252 |
| Education (% with tertiary) | -1.015 | 0.397 | -2.558 | 0.012 * |

Observations: 151
$R^2$: 0.3787, Adjusted $R^2$: 0.18254
F-statistic: 6.94956 on 10 and 114 DF, p-value: < 0.001

Appendix 5. Panel Data Regression for CIR Model (extended table)

| Variable | Coefficient | Std. Error | t-value | p-value |
|---|---|---|---|---|
| Digitalization Index (t-1) | -0.243 | 0.093 | -2.613 | 0.010 * |
| ICT (t-1) | -4.602 | 1.901 | -2.422 | 0.017 * |
| GDP per Capita | -0.127 | 0.191 | -0.662 | 0.510 |
| Inflation (%) | 0.434 | 0.127 | 3.423 | <0.001 *** |
| Interest Rate (%) | -1.196 | 0.333 | -3.593 | <0.001 *** |
| Interest Rate (t–1) (%) | -0.278 | 0.234 | -1.185 | 0.239 |
| CET1 Capital | 0.365 | 0.395 | 0.925 | 0.357 |
| NPL | 0.111 | 0.153 | 0.728 | 0.468 |
| Education (% with tertiary) | 0.313 | 0.531 | 0.588 | 0.557 |

Observations: 152
$R^2$: 0.5105, Adjusted $R^2$: 0.3616
F-statistic: 13.3282 on 9 and 115 DF, p-value: < 0.001