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The Impact of Information and Communication Technologies on Banks' Profitability Performance and Intermediation Costs: Evidence from European Countries

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Abstract

This paper examines how information and communication technology (ICT) shaped bank performance and intermediation costs in Europe over 2011–2021. We analyze a panel of 27 countries, covering EU members and selected non-EU economies. A composite, banking-anchored ICT index is constructed via principal component analysis (PCA) from ATM and branch intensity, fixed broadband and mobile subscriptions, and the shares of individuals using the internet and internet banking. Using country fixed-effects regressions and Dynamic OLS (DOLS), we find that higher ICT intensity is positively associated with profitability (ROA, ROE) and negatively associated with intermediation costs, with results that are robust across various specifications. The findings carry clear policy implications: targeted investment in digital infrastructure and skills, interoperable and efficient payment rails, secure data-sharing frameworks and cybersecurity standards, and supportive yet prudent regulatory environments can compress intermediation wedges and broaden access while mitigating transition frictions across heterogeneous banking systems. For practice, banks that prioritize process automation, data-driven pricing and risk tools, and disciplined channel optimization (including reconfiguration of branch/ATM networks) are better positioned to lift ROA/ROE and sustain lean cost-to-income profiles. Overall, prudent digitalization is associated with greater efficiency, competitiveness, and financial inclusion across European banking.

Keywords: ICT; bank profitability; intermediation costs; dynamic ordinary least squares, investment, digital economy, cybersecurity, European Union

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El impacto de las tecnologías de la información y la comunicación en el desempeño de rentabilidad y los costos de intermediación de los bancos: evidencia de países europeos

Resumen

Este artículo examina cómo las tecnologías de la información y la comunicación (TIC) configuraron el desempeño bancario y los costos de intermediación en Europa durante el período 2011-2021. Se analiza un panel de 27 países, que abarca a los Estados miembros de la UE y a determinadas economías no pertenecientes a la UE. Se construye un índice compuesto de TIC anclado en la banca mediante un análisis de componentes principales (ACP), a partir de la intensidad de cajeros automáticos y sucursales, las suscripciones a banda ancha fija y móvil y la proporción de individuos que utilizan internet y la banca electrónica. Mediante regresiones con efectos fijos por país y mínimos cuadrados ordinarios dinámicos (DOLS), encontramos que una mayor intensidad de TIC se asocia positivamente con la rentabilidad (ROA, ROE) y negativamente con los costos de intermediación, con resultados robustos en distintas especificaciones. Los hallazgos tienen claras implicaciones en las políticas: la inversión focalizada en infraestructura digital y en competencias, la existencia de sistemas de pago interoperables y eficientes, marcos seguros para el intercambio de datos y estándares de ciberseguridad, así como entornos normativos favorables pero prudentes, pueden reducir las cuñas de intermediación y ampliar el acceso, al tiempo que mitigan las fricciones de transición en sistemas bancarios heterogéneos. En la práctica, los bancos que priorizan la automatización de procesos, las herramientas de fijación de precios y de riesgo basadas en datos y la optimización disciplinada de los canales (incluida la reconfiguración de redes de sucursales y cajeros) están en mejor posición para incrementar el ROA/ROE y mantener perfiles de costos-ingresos más ajustados. En general, una digitalización prudente se asocia con una mayor eficiencia, competitividad e inclusión financiera en la banca europea.

Palabras clave: TIC; rentabilidad bancaria; costos de intermediación; Modelos de mínimos cuadrados ordinarios dinámicos, inversión, economía digital, ciberseguridad, Unión Europea.

INTRODUCTION

In the twenty-first century, information and communication technology (ICT) has played a pivotal role in reshaping business models within the financial services sector. Banks and other financial institutions face various challenges in adapting their business models; however, they have responded by reaching niche markets, leveraging new distribution channels, and developing innovative products. Strengthening business models through technological infrastructure has not only enhanced the productivity, efficiency, and market reach of financial institutions but has also benefited customers by enabling convenient and efficient financial transactions (Murinde et al., 2022). Moreover, the application of ICT principles, methodologies, policies, and implementation approaches in banking services has emerged as a critical consideration for all financial institutions. It serves as a fundamental requirement for maintaining banks' competitive advantage while also playing a direct role in influencing managerial decision-making processes, strategic planning, and the range of products and services offered in the banking sector (Ekwonwune et al., 2016). Empirical evidence indicates that ICT investment is a key driver of profitability and significantly contributes to both performance and competitiveness (Al-Amarneh et al., 2023).

Due to the benefits that ICT provides to banks in terms of profitability, financial performance, risk management, and customer satisfaction, numerous studies in the literature have investigated the influence of ICT on the banks' financial efficiency (Del Gaudio et al., 2020). A significant amount of research has found that the adoption and utilization of ICT, as well as the provision of services through online channels, have a positive influence on banks' profitability and financial performance (Al-Amarneh et al., 2023; Ciciretti et al., 2009; Kagan et al., 2005). Although investments in ICT and the adoption of its tools have benefited the banking industry, there is ongoing debate about how these advancements influence banks' financial performance. This uncertainty is partly captured by the "productivity paradox," also known as the "Solow paradox," articulated by Robert Solow in 1987. The paradox observes that, despite substantial investment in computers and information technology, measured productivity did not rise accordingly—a point Solow memorably summarized: "You can see the computer age everywhere but in the productivity statistics." Explanations typically emphasize lags, mismeasurement, and organizational bottlenecks that can obscure the gains from new technologies (Solow, 1987). While some studies support this paradox (Ho & Mallick, 2006; Shu & Strassmann, 2005), other studies link improvements in banks' financial performance to several ICT penetration indices. These indices include ICT capital accumulation, enhanced and advanced technological techniques, expansion of ICT investments, online and e-banking, credit card usage, ICT-enabled agents, and other forms of technological innovation.

This study aims to assess the impact of ICT diffusion on the financial performance and intermediation costs of banks across European countries. In addition, another objective of the study is to determine whether macroeconomic variables, used as control variables, influence banks' financial performance and intermediation costs. The primary reason for selecting European countries in this study is the finding, based on Eurostat data, that 69 percent of the population in these countries uses internet banking. The high rate of internet banking usage is expected to yield more robust results in the econometric model developed for this study.

Europe offers an instructive setting for studying the digital transformation of banking. The region combines high—but heterogeneous—digital adoption with a broadly common regulatory and payments architecture and diverse banking models (universal vs. relationship-based; varying branch intensity). Observing the period from 2011 to 2021, which spans post-crisis repair and the rapid shift to digital channels, yields rich cross-country and intertemporal variation to test whether digitalization is reflected in profitability (ROA, ROE) and/or in intermediation wedges (net interest margin, cost-to-income ratio).

This study contributes in two ways. First, it constructs a banking-anchored ICT index that captures usable digital capacity rather than mere availability, integrating sector-specific components (internet banking usage, ATMs, and branch intensity) with economy-wide enablers via principal components analysis (PCA). Second, it moves beyond profitability to jointly examine intermediation costs—outcomes central to financial efficiency and risk management—by linking the ICT index to ROA/ROE, net interest margins, and cost-to-income while conditioning on macroeconomic covariates. Methodologically, country fixed effects combined with panel DOLS mitigate endogeneity and serial correlation, supporting credible inference on where digital dividends materialize—on the income statement, within intermediation costs, or both—with clear implications for policymakers.

The study seeks to address several key questions. Specifically, it investigates whether the ICTs adopted by various countries have (1) an impact on banks' financial performance and (2) an effect on banks' intermediation costs. To provide econometric answers to these questions, the study employs panel data spanning the years 2011 to 2021. The ICT index was created using PCA. After constructing the index, this study examines the interaction between the dependent and independent variables using the fixed effects regression method, along with the dynamic ordinary least squares (DOLS) model. These methods help determine whether a statistically significant effect exists. The main reason for applying the DOLS method is its ability to eliminate endogeneity between the independent variables and error terms while also addressing autocorrelation in the error terms.

The remainder of this study is structured as follows: Section 2 reviews the relevant literature, covering both theoretical and empirical studies. Section 3 outlines the dataset and methodological framework. Section 4 presents and discusses the empirical findings. Section 5 provides a political discussion, and the final section offers general conclusions.

LITERATURE REVIEW

Globalization and the rapid pace of technological progress have brought about substantial changes across various sectors, including the financial industry. The banking sector, in particular, has undergone significant transformations, reshaping traditional business models. As a result, new concepts such as e-banking, e-money, and related innovations have emerged, reflecting the ongoing evolution in financial services (Al-Smadi & Al-Wabel, 2011). Empirical evidence in the literature suggests that financial institutions that leverage technology, particularly through ICT products, experience a reduction in operational risks. Moreover, several studies suggest that the adoption of ICT applications contributes to an improvement in banks' asset quality, which, in turn, positively impacts their financial performance (Al-Amarneh et al., 2023; Yang et al., 2018). Conversely, some studies argue that adopting ICT has either a negative or no statistically significant effect on a company's financial performance (Ho & Mallick, 2006). Solow (1987) refers to this phenomenon as a paradox, suggesting that ICT usage does not necessarily lead to substantial improvements in performance. The underlying rationale for this paradox is that if a firm's organizational structure is not adapted to accommodate new technology, optimal outcomes from such innovations cannot be expected.

In 2014, Rauf et al. examined the profitability of banks adopting ICT in Pakistan's banking sector and found that, in the long run, ICT adoption contributes positively to bank profitability. Gutu (2014) reported that e-banking services negatively affected the profitability of some Romanian banks, attributing this to customers' preference for traditional banking methods. Dabwor et al. (2017) demonstrated that the adoption of ICT and banks' financial performance in Nigeria are positively correlated. Similarly, Del Gaudio et al. (2020) found evidence that the adoption of ICT enhances financial performance and improves operational efficiency in European banks. Le et al. (2022) analyzed 27 Vietnamese banks (2007–2019) using DEA and BCQR and found that ICT developments significantly improved efficiency, supporting innovation- and digitalization-led reforms. Mohammed et al. (2023) examined the role of modern technologies in enhancing bank profitability in Iraq and, using questionnaire-based evidence, reported a statistically significant positive association between technology adoption and profitability. Mostafapoor et al. (2024) employed questionnaire-based regression analysis on Nepalese commercial banks and found that ICT channels—namely, internet banking, ATMs, mobile banking, POS, and e-payments—were each positively associated with bank productivity and profitability. Kayed et al. (2025) analyzed 13 Jordanian commercial banks and found that internal FinTech—an ICT-intensive innovation—was associated with higher profitability. Finally, Almadadha (2025) examined blockchain adoption in Australian banks, evaluating outcomes via ROA and ROE, and identified a positive association with financial performance, with evidence pointing to efficiency gains, improved cost management, and enhanced profitability.

Despite extensive scholarly research on the correlation between ICT and banks' financial performance, studies specifically investigating its impact on bank intermediation costs remain limited. A pioneering study in this field was conducted by Ho and Saunders (1981), who employed a two-step procedure to analyze the factors influencing banks' interest spread. This model was later expanded and tested by various researchers, including Allen (1988), Koyuncu et al. (2017), and McShane and Sharpe (1985), who assessed the influence of ICT adoption on banking intermediation efficiency. Their findings demonstrated that ICT usage enhances banking intermediation efficiency by reducing interest rate spreads and margins. Similarly, Yang et al. (2018) analyzed the profitability and cost efficiency of banks following the full adoption of e-banking. Their findings suggest that e-banking enhanced financial performance in the Chinese banking sector, as reflected in higher ROA, ROE, and net interest rate. Another study exploring the impact of ICT on banks' financial intermediation costs was conducted by Aguegboh et al. (2023). Their research analyzed how ICT influenced bank performance and interest margins—an essential measure of intermediation costs—in the Sub-Saharan African banking sector. Using panel analysis on data from 35 countries, their findings revealed that ICT had a short-term negative effect on banks' net interest margins, suggesting a temporary reduction in intermediation costs. Similarly, Nguyen et al. (2023) found that bank digitalization increases profitability by lowering intermediation costs (cost-to-income ratio) and boosting non-interest income.

The key distinction of our study from the existing literature lies in its focus on the usability of ICT in the banking sector rather than merely its quantitative presence. This study examines how infrastructure fosters financial innovation and drives technological advancements in the banking sector. To achieve this, in addition to the conventional ICT variables found in the literature, we incorporate banking sector-specific information and communication infrastructure variables to create a broader index. This index facilitates a more in-depth analysis of the correlation between the banking sector's financial performance and intermediation costs, providing a more nuanced understanding of ICT's impact on banking efficiency.

DATA AND METHODOLOGY

Data and Model

This study examines the influence of ICT on banks' financial performance and intermediation costs, using panel data analysis across 27 European countries, including those in the European Union and selected non-EU economies, from 2011 to 2021. Table 1 lists the European countries included in the study. The exclusion of other countries is due to data unavailability.

Table 1

List of European Countries

Austria	Hungary	Poland
Belgium	Iceland	Portugal
Czech Republic	Ireland	Slovakia
Denmark	Italy	Slovenia
Estonia	Latvia	Spain
Finland	Lithuania	Sweden
France	Luxembourg	Switzerland
Germany	Netherlands	Turkey
Greece	Norway	United Kingdom

Source: Own elaboration.

The model developed here is based on existing research examining the relationships among ICT, financial performance, and intermediation costs in the banking sector. The models used in this study are presented below:

$$ROA_{it} = \beta_{i0} + \beta_{i1}\, ICT_{it} + \beta_{i2}\, CIR_{it} + \beta_{i3}\, GDP_{it} + \varepsilon_{it}$$

$$ROE_{it} = \beta_{i0} + \beta_{i1}\, ICT_{it} + \beta_{i2}\, CIR_{it} + \beta_{i3}\, GDP_{it} + \varepsilon_{it}$$

$$IMI_{it} = \beta_{i0} + \beta_{i1}\, ICT_{it} + \beta_{i2}\, CIR_{it} + \beta_{i3}\, GDP_{it} + \varepsilon_{it}$$

where i represents a country ($i = 1, ..., 27$), while t denotes the period ($t = 2011, ..., 2021$). The variable ICT_{it} signifies the Information and Communication Technology Index for country i in year t; ROA_{it} represents the Return on Assets; ROE_{it} denotes the Return on Equity; IMI_{it} refers to the Interest Margin to Gross Income ratio; CIR_{it} corresponds to the Cost-to-Income Ratio of banks; and GDP_{it} stands for the Gross Domestic Product per capita. The term ε_{it} represents the error term. The dataset utilized in this study is sourced from reputable international institutions. Data on the Interest Margin to Gross Income (IMI) were sourced from the International Monetary Fund (IMF), while statistics concerning the use of the internet for banking services (IIB) were obtained from Eurostat. The remaining variables were compiled from the World Development Indicators (WDIs) and the World Bank's Open Data platforms. Operational definitions, units, and construction details for all variables are reported in Table 2. Following Del Gaudio et al. (2020), Huang et al. (2022), and Saba et al. (2023), we construct the ICT index via PCA on standardized inputs to summarize common variation in ICT penetration, while reducing dimensionality by transforming correlated indicators into orthogonal components.

Econometric Methodology

Countries' financial systems consist of multidimensional variables. In studies employing multivariate analysis methods, examining the structure of the correlation or variance-covariance matrix of variables holds significant importance. One of the widely used multivariate analysis techniques is PCA, originally introduced by Hotelling in 1933. PCA is a method that transforms a dataset composed of p original variables into a smaller set of principal components, which are linear components of the original set. From a data matrix containing p variables, a maximum of p principal components can be derived (Johnson & Wichern, 2002), as shown in Equation 1.

Table 2.

Operational Definitions of Variables

Group	Variable (code)	Definition	Unit / Construction
Dependent	ROA	Return on Assets = Net income / Total assets	% (annual)
	ROE	Return on Equity = Net income / Shareholders' equity	% (annual)
	IMI	Interest Margin to Gross Income = Net interest income / Total operating (gross) income	% (annual)
ICT Index Inputs	ATM	Automated teller machines per 100,000 adults	Count per 100,000 adults
	CBB	Commercial bank branches per 100,000 adults	Count per 100,000 adults
	MCS	Mobile cellular subscriptions per 100 people	Subscriptions per 100 people
	FBS	Fixed broadband subscriptions per 100 people	Subscriptions per 100 people
	IUI	Individuals using the internet	% of population
	IIB	Individuals using the internet for internet banking	% of population
Controls	GDP	GDP per capita growth (annual)	% (annual growth)
	CIR	Bank cost-to-income ratio	%

Source: Own elaboration.

$$PC_1 = a_{11} X_1 + a_{12} X_2 + \cdots + a_{1p} X_P$$
$$PC_2 = a_{21} X_1 + a_{22} X_2 + \cdots + a_{2p} X_P \qquad [1]$$
$$PC_P = a_{P1} X_1 + a_{P2} X_2 + \cdots + a_{Pp} X_P$$

The principal components, denoted as PC_1, PC_2...., PC_p represent the p principal components, while a_{ij} indicates the weight of the jth variable in the ith principal component. The principal component weights (a_{ij}) are computed to satisfy the following condition: The first principal component accounts for the largest proportion of total variance in the dataset, with each subsequent component capturing a progressively smaller share (Equation 2).

$$\text{b) } a_{i1}^2 + a_{i2}^2 + \cdots + a_{ip}^2 = 1 \text{ (i=1,2,...,p)} \qquad [2]$$
$$\text{c) } a_{i1}^2 \, a_{j1}^2 + a_{i2}^2 \, a_{j2}^2 + \cdots + a_{ip}^2 \, a_{jp}^2 = 0 \ (i \neq j)$$

In PCA, each component is calculated as a linear function of all the components included in the analysis. The resulting PC, in turn, makes the maximum possible contribution to the total variance. According to the second condition, the sum of the squares of the principal component weights must equal one. To meet this condition, all variables in the analysis must be normalized.

This study employs the widely used Min-Max normalization technique, as frequently cited in the literature. The Min-Max normalization technique adjusts data values based on the minimum and maximum values within the dataset. In this method, the highest value is scaled to 1, the lowest value to 0, and all other values are transformed accordingly within this range. The Min-Max normalization formula is presented in Equation 3 (Petrovska & Mihajlovska, 2013).

$$X^n = \frac{X_i - X_{min}}{X_{max} - X_{min}} \qquad [3]$$

In the formula, X^n represents the normalized data; X_i denotes the input value; X_{min} is the smallest number in the dataset; and X_{max} is the largest number in the dataset. After the variables are standardized, the weights for their contribution to the index must be calculated. These weights are determined using PCA. In PCA, the weights reflect the impact of a one-standard-deviation change in a variable on the index.

Various methods have been developed for estimating the cointegration vector in panel datasets. One such method is the panel Dynamic Ordinary Least Squares (DOLS) approach, introduced by Pedroni (2000). The DOLS method incorporates dynamic elements into the model, addressing biases present in static regression (Pedroni, 2000). Unlike the FMOLS estimator, the DOLS estimator can estimate each cross-section individually. The panel cointegration coefficients are then obtained by calculating the arithmetic mean of the estimated cointegration coefficients. The estimation of the DOLS regression model is formulated as follows (Equation 4).

$$Yit = \alpha_i + \beta_i x_{it} + \sum_{k=-Ki}^{K_i} \gamma_{ik} \Delta x_{i,t-k} + \mu_{it} \qquad [4]$$

In this regression model, $-K$ and K_i represent the lead and lag lengths, respectively. The model assumes no cross-sectional dependence among panel units, allowing estimation of the panel cointegration vector and individual estimates for each cross-section. In the second stage, the arithmetic means of the cointegration coefficients obtained from the DOLS estimations for each cross-section are calculated to derive the overall panel cointegration coefficient (Pedroni, 2000).

RESULTS

PCA Method Related to the ICT Index

To construct the ICT index, we rescaled all variables with Min–Max normalization. We then ran PCA and computed the eigenvalues for each component, which indicate the proportion of variance explained. Component retention followed the Kaiser rule (eigenvalue > 1), so only dimensions capturing a substantive share of common variance were kept, while those below the threshold were excluded. Table 3 reports the total and cumulative variance explained by the retained components.

Table 3

Eigenvalues of PCs

Number	Value	Difference	Proportion	Cumulative value	Cumulative proportion
PC 1	3.160763	2.157036	0.6322	3.160763	0.6322
PC 2	1.003727	0.539423	0.2007	4.164490	0.8329
PC 3	0.464304	0.255844	0.0929	4.628794	0.9258
PC 4	0.208460	0.045714	0.0417	4.837254	0.9675
PC 5	0.162746	---	0.0325	5.000000	1.0000

Source: Own elaboration.

Table 3 shows that only two of the five variables used to construct the ICT index have variances greater than 1. These components are selected for the index because their eigenvalues exceed 1, consistent with the Kaiser criterion. The cumulative ratio represents the proportion of total variance explained by the PC. Together, the two PC with eigenvalues above one account for 83.29 % of the total variance. In forming the final ICT index, these components are weighted so that their combined weights sum to one, based on their respective contributions to variance. Table 4 illustrates the eigenvectors corresponding to each principal component.

Table 4 reports the component loadings (eigenvectors). Positive loadings indicate direct association with the component; negative loadings indicate inverse association. Squared loadings give each variable's contribution to a component. For PC1, the largest loadings are FBS (0.524), IUI (0.513), and IIB (0.512), accounting for 27.45 %, 26.29 %, and 26.21 % of PC1, respectively (ATM 19.96 %, MCS ≈ 0.10 %). PC2 is dominated by MCS (loading 0.995; 99.01 % of PC2), with all other variables contributing <1 %. Figure 1 (orthonormal loadings) illustrates these relationships and the opposite direction of MCS relative to the other indicators.

Table 4

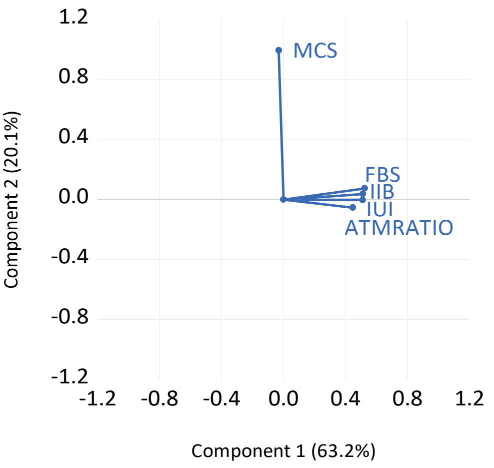
Eigenvectors of PCs

Variables	PC 1	PC 2
ATM	0.446721	-0.053746
IUI	0.512700	-0.005670
IIB	0.511918	0.037539
MCS	-0.031410	0.995059
FBS	0.523959	0.074345

Source: Own elaboration.

Figure 1

Orthonormal Loadings



Source: Own elaboration.

Figure 1 shows that ATM, IUI, IIB, and FBS cluster along PC1 (63.2 % of variance), indicating strong, positive loadings on a common dimension. By contrast, MCS loads almost entirely on PC2 and is nearly orthogonal to the other variables, suggesting it captures a distinct facet of ICT rather than moving with the PC1 cluster. To improve interpretability, we applied an orthogonal rotation (Varimax). Rotation leaves the total variance and orthogonality unchanged but redistributes loadings to achieve a simpler structure—some loadings increase while others diminish—thereby sharpening factor meaning. The rotated loadings obtained via Varimax are reported in Table 5.

Table 5

Rotation-Factor Matrix

Rotation method: Orthogonal Varimax Variables	Factor 1	Factor 2
ATM	0.681663	0.158796
IUI	0.866975	0.115299
IIB	0.878387	0.039071
MCS	-0.019879	-0.203714
FBS	0.912709	0.020883

Source: Own elaboration.

Table 5 presents the Varimax-rotated orthogonal matrix. PC1 exhibits strong, positive loadings for FBS (0.913), IIB (0.878), IUI (0.867), and ATM (0.682), indicating that these indicators co-move on the primary dimension of the ICT index. MCS has a near-zero loading on PC1 (−0.020) and a small negative loading on PC2 (−0.204), suggesting it captures a distinct aspect rather than the common PC1 cluster. As is standard with orthogonal rotation, total explained variance and component orthogonality are preserved; rotation simply redistributes loadings to yield a simpler, more interpretable structure.

To aggregate components into a single index, we weight PCs by their share of explained variance among the retained components. With PC1 = 63.22 % and PC2 = 20.07 % (total retained = 83.29 %), the weights are:

$$w1 = \frac{63.22}{83.29} = 0.759, \qquad W2 = \frac{20.07}{83.29} = 0.241$$

and the index is:

$$\text{ICT} = 0.759\text{PC1} + 0.241\text{PC2}$$

For interpretation at the variable level, squared loadings can be used to gauge each variable's contribution to a given component.

After determining the sub-indicator weights through factor analysis, the ICT index ratios were multiplied by these weights to construct the sub-indicator set. Subsequently, the sub-indicator values were aggregated to calculate the ICT index values for the period from 2011 to 2021. In Table 6, the variables incorporated into the components were assigned weights based on their factor loadings.

Table 6

Weighting of Index Components

Variables	Weights
ATM	0.3519
IUI	0.3904
IIB	0.3975
MCS	0.2634
FBS	0.4154

Source: Own elaboration.

According to Table 6, the factor loadings of the variables included in the index component are relatively close to one another. Among these, FBS (41.54 %), IIB (39.75 %), and IUI (39.04 %) had the highest weights in the ICT index.

Preliminary Analyses

After the ICT index has been constructed, the descriptive statistics for both the dependent and independent variables are summarized in Table 7.

Table 7

Descriptive Statistics of the Variables

Variables	Mean	Median	Std. Dev.	Skewness	Kurtosis	Jar. Bera	Obs.
ROA	0.788373	0.774093	2.686252	4.695528	113.9652	221676.4	429
ROE	6.889333	8.609584	12.37918	-4.198777	33.74239	18154.09	429
IMI	54.58093	56.55325	14.11756	-0.685123	3.672548	41.64689	429
ICT	-2.540217	-0.100649	1.032936	0.062286	2.446266	5.758244	429
CIR	58.92273	57.96929	12.98845	0.525417	4.635096	67.52801	429
GDP	1.969311	1.846520	3.916066	-0.094417	7.122845	304.4739	429

Source: Own elaboration.

Table 7 reports descriptive statistics for 429 observations. Means and medians are close for most variables (e.g., ROA, IMI, CIR, GDP), but the gap is larger for ICT. When examining the standard deviation, the highest value is observed for the IMI variable, indicating the most dispersed distribution. The kurtosis values range from 3.67 to 113.96, indicating an asymmetric distribution. In terms of skewness, a negative value indicates right-skewness, while a positive value signifies left-skewness. The skewness values of the variables were equally distributed.

To assess potential multicollinearity among regressors, we computed Spearman pairwise correlations and variance inflation factors (VIF). As rule-of-thumb benchmarks, correlations above 0.80 are indicative of multicollinearity (Gujarati, 2002), and VIF values exceeding 10 suggest problematic collinearity (Curto & Pinto, 2011). The correlation matrix and VIF values are illustrated in Table 8.

Table 8

Correlation Matrix and VIF

	ROA	ROE	IMI	ICT	CIR	GDP
ROA	1.000					
ROE	0.7894	1.000				
IMI	-0.0313	-0.0725	1.000			
ICT	0.1563	0.1342	-0.0928	1.000		
CIR	-0.5455	-0.5631	-0.0832	0.0160	1.000	
GDP	0.3605	0.2837	0.0793	0.0908	-0.1428	1.000
VIF				1.0158	1.0014	1.0148

Source: Own elaboration.

As shown in Table 8, the largest correlation is between ROA and ROE ($\rho = 0.7894$), as expected for profitability measures, and it remains below the 0.80 threshold. Correlations among the remaining regressors are modest ($|\rho| \leq 0.15$). VIFs are essentially unity (≈ 1.001–1.016), confirming the absence of multicollinearity. We therefore retain all variables and proceed to test for cross-sectional dependence and heteroskedasticity using the Breusch–Pagan (1980) LM, Pesaran LM, bias-corrected LM, Pesaran CD (2004), and modified Wald (2000) tests; results are reported in Table 9.

Table 9

Diagnostic Tests

Tests	Model 1		Model 2		Model 3	
	Chi-Square	Prob.	Chi-Square	Prob.	Chi-Square	Prob.
Hausman test statistics	14.06712	0.000*	12.647815	0.000*	11.060063	0.000*
Breusch-Pagan (1980) LM test	1202.407	0.000*	1342.205	0.000*	1943.235	0.000*
Pesaran scaled LM test (2004)	11.98561	0.000*	15.61703	0.000*	31.22952	0.000*
Bias-corrected scaled LM test	10.03561	0.000*	13.66703	0.000*	29.27952	0.000*
Pesaran (2004) CD test	7.634694	0.000*	5.010347	0.000*	6.530218	0.000*
Modified Wald (2000) test	4.712163	0.000*	3.986132	0.000*	4.124784	0.000*

Note. * indicates that the variables are significant at the 0.01 level.

Source: Own elaboration.

As shown in Table 9, the Hausman statistic is significant ($p < 0.01$) across all models, indicating that we reject H0 and prefer the fixed-effects specification. The LM and CD tests are also significant ($p < 0.01$), rejecting H_0 of no cross-sectional dependence; hence, CSD is present. The modified Wald test is significant ($p < 0.01$), indicating groupwise heteroskedasticity. Given these features, inference should rely on covariance estimators robust to both heteroskedasticity and cross-sectional dependence.

Since cross-sectional dependence is detected, we employ a second-generation panel unit root procedure. Specifically, we use the CADF–CIPS test; its null hypothesis is that the series has a unit root, which we reject when $p < 0.05$. Test statistics and p-values are reported in Table 10.

Table 10

CADF-CIPS Unit Root Test Results

Variables	Level values Zt-bar (Prob.)
ROA	-2.79245 (<0.01) *
ROE	-2.92088 (<0.01) *
IMI	-2.88092 (<0.01) *
ICT	-2.98668 (<0.01) *
CIR	-2.94346 (<0.01) *
GDP	-2.58893 (<0.01) *

Note. * indicates that the variables are significant at the 0.01 level.

Source: Own elaboration.

As reported in Table 10, the CADF–CIPS $\bar{Z}$_t statistics are significant at the 1 % level for all variables ($p < 0.01$). Thus, we reject the null hypothesis of a unit root and conclude that ROA, ROE, IMI, ICT, CIR, and GDP are level-stationary. Given cross-sectional dependence in the panel, these second-generation results justify proceeding with the variables in their levels rather than differencing them.

Model Estimation Results

To analyze whether a significant interaction exists between the dependent and independent variables, both the fixed-effects regression method and the DOLS regression model were applied. The DOLS method, developed by Pedroni (2000), integrates the leads and lags of the first differences of the independent variables. This approach helps eliminate endogenous feedback effects from the dependent variable to the independent variables. Moreover, the DOLS method was chosen for its ability to address endogeneity between the independent variables and the error terms, as well as to mitigate autocorrelation in the error terms. The panel data analysis results are reported in Table 11.

Table 11

Panel Data Analysis Results

Dependent variables	Fixed effects regression			DOLS		
	ROA	ROE	IMI	ROA	ROE	IMI
	Independent variables					
ICT	0.223625*** (0.0530)	1.921429* (0.0001)	-0.674611** (0.0483)	0.227311** (0.0226)	1.881035* (0.0067)	-1.290920** (0.0326)
	Control variables					
CIR	-0.085542* (0.0000)	-0.271230* (0.0000)	0.097226** (0.0205)	-0.037784* (0.0047)	-0.292336* (0.0017)	0.025580 (0.7502)
GDP	0.081232** (0.00102)	0.642380* (0.0000)	-0.108320 (0.2446)	0.238878* (0.0000)	1.628246* (0.0000)	0.065160 (0.8004)
C	5.668793* (0.0000)	21.60592* (0.0000)	49.06542* (0.0000)			
R-sqr.	0.328141	0.443118	0.787656	0.795583	0.701746	0.858970
Adj. R-sqr.	0.256963	0.384120	0.765160	0.655765	0.497745	0.762509
F-statis.	4.610099* (0.0000)	7.510748* (0.0000)	35.01264* (0.0000)			
Hannan-Quinn criter.	4.766959	7.635004	6.933661			
Durbin-Watson stat.	2.086106	1.672923	0.805918			
Observations	429	429	429	390	390	390

Note. *, **, and *** respectively indicate statistical significance of 1 %, 5 %, and 10 %.

Source: Own elaboration.

An examination of the analysis results presented in Table 11 shows that the probability value of the F-statistic, which indicates the overall significance of the model, is statistically significant at the 99 % confidence level. The model's strong descriptive power further substantiates the accuracy of the explanatory variables included in the analysis. The findings demonstrate that advancements in information and communication technologies (ICT) have a positive influence on banks' return on assets (ROA) and return on equity (ROE), while concurrently reducing intermediation costs. According to the fixed-effects regression and DOLS results, a one-unit increase in a country's ICT level leads to an average increase of 0.22 units in the banking sector's ROA. Furthermore, a one-unit increase in ICT level raises the banking sector's ROE by 1.92 units based on the fixed-effects regression method and by 1.88 units according to the DOLS method. Conversely, the same one-unit increase in ICT level is associated with a reduction in the banking sector's net interest margin, with a decline of 0.67 units in the fixed-effects regression and 1.29 units in the DOLS method. Regarding the control variables, a one-unit increase in GDP has a positive effect on both ROA and ROE while contributing to a reduction in intermediation costs. In contrast, the CIR variable negatively impacts banks' ROA and ROE while exerting an increasing effect on intermediation costs. The findings of this study support the theoretical premise that the proliferation of ICT can enhance banks' financial performance. Additionally, since ICT adoption is expected to reduce operational costs in the banking sector, the study further corroborates the theory that ICT expansion lowers intermediation costs.

POLICY DISCUSSION

The study's results emphasize that advancements in ICT have a positive impact on banks' financial performance while reducing intermediation costs. The findings lend empirical support to the view that the expansion of ICT can enhance banks' financial performance (Al-Amarneh et al., 2023; Ciciretti et al., 2009; Dabwor et al., 2017; Del Gaudio et al., 2020; Delgado et al., 2007; Hasan et al., 2010). These results highlight the substantial impact of ICT investments on the structure and operations of the banking sector. By leveraging technology, banking transactions can be conducted more efficiently, and firms can market their products more effectively (Bagudu et al., 2017). For instance, banks can develop detailed customer databases, enabling them to refine commercial strategies through data mining and to predict clients' interest in specific financial products, thereby facilitating targeted marketing (Manoj, 2016). Furthermore, technology directly influences the product set offered by banks, supporting revenue generation.

In addition, the expansion of ICT helps reduce operating costs in the banking sector, consequently lowering intermediation costs (Koyuncu et al., 2017). The adoption of digital technologies enhances transaction efficiency, reduces expenditures, and enables a more effective allocation of financial resources (Chhaidar et al., 2023; Gomber et al., 2018). This pattern is consistent with structural changes in banks' revenue composition: when other revenue sources are volatile, relatively stable income from payment services contributes to overall stability (Del Gaudio et al., 2020; Koyuncu et al., 2017). At the same time, policymakers should recognize transitional frictions and heterogeneity in effects across institutions and markets, as evidenced by neutral or adverse outcomes in some contexts (Ho & Mallick, 2006).

Eurostat's 2023 Digital Economy and Society Index (DESI) highlights how economies such as Finland, Denmark, and the Netherlands are at the forefront of digital transformation, integrating advanced technologies into multiple sectors. This digital integration has significantly improved key performance indicators in the banking sector, particularly in operational efficiency, customer experience, and financial accessibility. Notably, in these countries, internet banking adoption rates have surged, reaching an impressive 97 percent. (European Central Bank, 2025; European Commission, 2021; Eurostat, 2024). From a banking-sector performance perspective, the European Banking Federation's 2024 report indicates that countries like Sweden and Finland demonstrate strong performance, with high ROA and ROE attributed to efficient practices and stable macroeconomic conditions (Saravia & Le Grusse, 2024). Conversely, Greece and Italy report lower performance metrics, reflecting economic difficulties and higher levels of non-performing loans (Saravia & Le Grusse, 2024). Overall, the correlation between ICT adoption and banking performance suggests that countries with higher digital integration tend to achieve better financial outcomes, underscoring the role of digital transformation in enhancing banking efficiency and profitability across Europe.

Practical solutions for lower-digital-penetration countries within our sample. To accelerate banks' digital transformation in settings such as Latvia, Lithuania, and Greece, four policy levers are particularly actionable: (i) reduce onboarding frictions via national e-ID and risk-based remote e-KYC to cut account-opening time and costs; (ii) targeted broadband and basic digital-skills programs for priority groups (e.g., older cohorts, micro-SMEs) to create effective demand for online banking; (iii) fintech–bank partnerships under clear regulatory sandbox templates (e.g., account aggregation, e-invoicing, instant payments) so incumbents can adopt proven solutions without large upfront IT overhauls; and (iv) public-sector digitalization as a demand anchor (tax/fee payments and transfers on digital rails), which shifts routine transactions online and strengthens incentives for banks to invest in digital channels. These measures provide policymakers in lower-digital-penetration settings in our sample with an actionable pathway to accelerate banks' digital transformation.

Policy guidance for governments and central banks. Public authorities can accelerate ICT adoption and reduce intermediation costs through a focused set of instruments. First, national e-ID and risk-based remote e-KYC enable fast and low-cost onboarding for households and SMEs, thereby expanding the formal use of digital channels. Second, instant payments and RTGS modernization lower transaction frictions and support efficient liquidity management across banks. Third, data-sharing and open-banking rules (with clear consent and interoperability standards) allow secure use of customer data, fostering competition, process automation, and cost efficiencies. Fourth, proportionate regulatory sandboxes enable incumbents to adopt tested fintech solutions (e.g., account aggregation, e-invoicing) without incurring large upfront IT overhauls. Finally, public digital payments—including digital tax/fee payments and government-to-person transfers—shift routine transactions online and strengthen banks' incentives to invest in digital channels.

The study's findings highlight how ICT contributes to greater financial efficiency and cost reduction in intermediation. However, for this potential to be fully realized, policymakers should develop strategies that take into account the differences within Europe. In particular, in countries at earlier stages of digitalization within our sample, deficiencies in digital infrastructure and skills hinder the transformation of the banking sector. Therefore, increasing ICT investments and implementing policies that support digital transformation in these countries is critical. First, to bridge the digital divide, targeted financial support mechanisms should be established for less digitally advanced economies. Expanding broadband networks, enhancing digital skills, and investing in financial technologies (fintech) are key enablers of banking sector transformation. Greater use of funding instruments, such as the European Regional Development Fund (ERDF), alongside targeted incentives, including low-interest loans and grants, can accelerate this process, supporting financial inclusion and enhancing economic resilience.

Secondly, it is essential for European countries to adopt education programs and policy measures that strengthen digital skills across the population and institutions. Although Latvia and Lithuania have made progress in digital literacy, gaps remain—especially in more advanced and domain-specific competencies, such as digital finance, cybersecurity, and data analytics. To address these challenges, establishing and expanding training, certification, and continuing education programs is necessary to enhance digital competencies at both individual and institutional levels. Moreover, fostering closer collaboration between universities, vocational institutions, and the private sector can help align curricula with industry needs and develop a workforce proficient in emerging technologies (including fintech). Such efforts can help narrow the skills gap and accelerate digital transformation, provided they are accompanied by supportive infrastructure, governance, and incentive structures.

Third, regulatory reforms should be implemented to expand digital banking services and enhance financial inclusion across European countries. In developing nations, limited access to digital banking services restricts financial accessibility. To address this, regulatory frameworks should be established to strengthen digital banking infrastructure and promote services such as mobile banking. Additionally, policies that encourage collaboration between financial technology (fintech) companies and traditional banks should be developed to foster innovative financial solutions.

Fourth, establishing a robust monitoring and evaluation framework is imperative for assessing the long-term impact of digital transformation on the banking sector across European economies. Such a framework should incorporate systematic and periodic assessments of how digital investments influence banking performance, intermediation costs, and overall financial stability. By leveraging empirical data, policymakers can make informed, evidence-based decisions to refine regulatory approaches and optimize digital transformation strategies. Furthermore, cross-country comparisons of successful digitalization policies, alongside the dissemination of best practices, would not only enhance policy coherence across the region but also provide valuable insights for economies at different stages of financial and technological development.

In conclusion, the findings demonstrate the potential of ICT to enhance financial performance and reduce costs in the banking sector. To fully realize this potential, policymakers should develop strategies that take into account the differences within Europe. Establishing a comprehensive monitoring framework and sharing successful implementation models will help bridge the digital divide, ultimately making the banking sector more efficient and effective.

CONCLUSIONS

This study makes a substantial contribution to the academic literature by analyzing the influence of ICT adoption on banks' financial performance and intermediation costs across European countries. The findings demonstrate that the adoption of ICT plays a crucial role in enhancing banking performance and reducing costs within the industry. An increase in ICT adoption levels positively affects the financial performance of the banking industry while concurrently lowering intermediation costs. Moreover, this relationship highlights the potential of financial inclusion to expand access to financial services, enhance economic participation, and foster overall financial stability.

Additionally, the beneficial impact of ICT on banks' financial performance highlights the necessity for financial institutions to integrate technological advancements into their strategic frameworks. The findings suggest that increased ICT adoption enhances ROA and ROE while reducing intermediation costs, thereby reinforcing efficiency gains associated with digital transformation.

Beyond its contribution to the literature, the study's findings serve as an important guide for policymakers in European countries. Given Europe's emphasis on financial stability and digital innovation, promoting the adoption of ICT in the banking sector can enhance the efficiency of financial intermediation processes, thereby contributing to economic growth. Policies that support technological investments—such as regulatory frameworks facilitating digital banking solutions, cybersecurity measures, and financial inclusion initiatives—can further strengthen the banking system. Moreover, as ICT adoption reduces intermediation costs, policymakers can leverage these findings to design policies that enhance competition and facilitate financial accessibility. This approach can help establish a more inclusive and resilient banking sector across Europe, strengthening financial stability and fostering sustainable economic growth. Rather than singling out one country, we emphasize transferable practices common among higher-digital-integration peers within our panel—such as national e-ID with remote e-KYC, instant payments, open-banking/data-sharing standards, and public digital payments—as pragmatic elements that other European economies can adapt to local conditions.

The study's findings are also of great relevance to senior bank executives. One of the key challenges banks face in modernizing their ICT infrastructure is the need to reduce staff numbers while retraining the workforce. Technology experts play a critical role in helping banks understand the potential benefits of technological advancements, particularly in terms of cost efficiency and innovation in the banking sector. Such developments can facilitate access to new customer segments, encourage the adoption of advanced tools, and enable the implementation of more efficient systems.

For future research, a broader scope should be adopted, utilizing different methodologies and datasets to further analyze the impact of ICT in the banking sector. This could include bank-level panels to examine whether ICT gains are heterogeneous by institution size or scope (e.g., ICT × size interactions). In particular, a comprehensive index should be developed to measure the effects of emerging financial technologies such as fintech, blockchain, and mobile banking on banks' profitability and intermediation costs. Additionally, to deepen the macroeconomic perspective, factors such as interest rates, inflation, and policy changes should be integrated into the model to assess their impact on financial stability. Comparative studies examining the differences between developed and developing economies should also be conducted to assess the impact of regulatory frameworks. Alternative econometric models can be employed to better establish causality, while time-series analyses can help predict long-term effects. Finally, a micro-level examination of the cost advantages of ICT in the banking sector, focusing on its impact on risk management, credit allocation processes, and customer behavior, can contribute to the development of sectoral policies. This approach would offer a deeper insight into the role of technological transformation in the financial system, particularly in relation to sustainable economic growth and financial inclusion.

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DECLARATION OF USE OF AI

The authors used AI-assisted tools only for English-language editing (grammar, spelling, style, and minor rephrasing) and for reference/format consistency at the late-drafting stage. No AI system was used to generate research ideas, design the study, collect or analyze data, interpret results, select or cite literature, or draw conclusions. All statistical analyses, tables/figures, and policy inferences were produced and verified by the authors.

Where AI was used for copyediting, the outputs were reviewed line by line and corrected by the authors to ensure accuracy and preserve the original intent. No confidential, proprietary, or personally identifiable data were uploaded to AI tools. The authors take full responsibility for the content of the manuscript.

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