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Digital technologies and financial inclusion in WAEMU: Exploring heterogeneous effects across the distribution of financial inclusion

Pousbila DIANDA

Center for Economic and Social Studies, Documentation and Research (CEDRES), Thomas SANKARA University, Ouagadougou, Burkina Faso

Abstract--This paper investigates the heterogeneous impact of Information and Communication Technologies (ICTs) on financial inclusion in the West African Economic and Monetary Union (WAEMU) over the period 2006–2022. To account for endogeneity, unobserved heterogeneity, and distributional differences across countries, the study employs the Method of Moments Quantile Regression (MMQR) approach. The findings reveal that ICT development significantly promotes financial inclusion, although the magnitude of the effects varies across the distribution of inclusion levels. Mobile telephony emerges as the most effective instrument for expanding financial inclusion, particularly in countries characterized by low initial levels of inclusion, thereby serving as a mechanism for financial catch-up. Internet diffusion also contributes positively by strengthening the geographic outreach and accessibility of digital financial services. In contrast, fixed-line telephony does not exert a significant influence, reflecting a technological leapfrogging process in which mobile technologies substitute for traditional communication infrastructure. The robustness of these results is confirmed through instrumental variable two-stage least squares (IV-2SLS) estimations. Based on these findings, the study recommends expanding mobile and broadband infrastructure, promoting the integration of digital financial services within traditional financial institutions, strengthening digital literacy, and enhancing cybersecurity frameworks to support broader and more secure financial inclusion across WAEMU countries.

Keywords--Financial Inclusion, ICT, Mobile Telephony, Internet, MMQR, WAEMU.

1. Introduction

The rapid development of information and communication technologies (ICTs) has profoundly transformed the financial sector, particularly in developing countries. The rise of digital financial services is in line with theories of financial innovation and banking regulation (Frame & White, 2009; Silber, 1975), which highlight the structuring role of technological progress in reducing transaction costs, expanding access to financial services, and reconfiguring intermediation models. These innovations have fostered the emergence of dematerialized financial services that are accessible at low cost and distributed via digital channels, thereby contributing to an unprecedented democratization of access to financial services, particularly in developing countries (Claessens et al., 2002; Moufakkir & Qmichchou, 2020). Digital finance is now recognized as a key driver of financial inclusion, understood as effective access to and use of formal financial services tailored to the needs of individuals and businesses (Guérineau & Jacolin, 2014). Financial inclusion is an essential pillar of economic and social development strategies because of its role in reducing inequalities, promoting entrepreneurship, improving household resilience, and stimulating inclusive growth (Dianda, 2025; Li et al., 2025; Pomeroy et al., 2020; Tay et al., 2022). This momentum has accelerated in the wake of the COVID-19 pandemic, which has increased the use of digital payments and electronic money. In fact, approximately 40% of adults in developing economies, excluding China, have made digital merchant payments, whereas more than one-third have paid a utility bill from a digital account for the first time since the start of the pandemic (Demirgüç-Kunt et al., 2022). These developments illustrate the growing role of ICT as a vehicle for financial inclusion in times of economic shock.

Theoretically, the link between ICT and financial inclusion can be understood through theories of innovation diffusion and technology adoption. Rogers (1962) argues that the diffusion of an innovation depends on its accessibility and its ability to spread throughout the economic space. In the financial sector, the development of ICT contributes to the geographical expansion of financial services by reducing the constraints associated with distance and the organization of distribution networks. Similarly, Davis' Technology Acceptance Model (TAM) (1989) emphasizes the role of perceived usefulness and ease of use in the effective adoption of technologies. The empirical literature identifies several channels through which ICTs promote financial inclusion. First, they significantly reduce the costs of providing financial services through process automation, reduce staffing requirements, and lead to the emergence of new business models (Fogaat et al., 2024; Khallouli, 2014; Ogunrinde, 2023; Sultana & Khan, 2016). Second, they improve the accessibility of financial services by circumventing geographical and institutional constraints, particularly in rural or underserved areas (Dahiya et al., 2024; Dianda, Thiombiano, et al., 2025; M. Ouedraogo, 2021). Third, ICTs contribute to improving the quality of financial services by enabling the development of more personalized products that are better suited to users' needs (Hornuf et al., 2025; Terfas & Lezghed, 2023). Finally, they reduce information asymmetries and capital market imperfections, thereby enhancing the efficiency of financial intermediation (Allen et al., 2018). These developments are consistent with the findings of the new endogenous growth theory, according to which the development of the financial system plays a central role in the diversification of

technological risk, the efficient allocation of savings, and the specialization of investments (Bencivenga & Smith, 1991; Berthélemy & Varoudakis, 1994; Levine, 1991).

Despite this favorable theoretical framework, the empirical results remain mixed. Several studies highlight obstacles related to data security, poor system interoperability, digital skill gaps, and user confidence, particularly in rural areas (Ogunode & Akintoye, 2023; Parvin & Panakaje, 2022). Other studies have shown that the rapid expansion of digital financial services may, in the short term, generate risks to banking efficiency and stability (Syed et al., 2022) or exacerbate vulnerabilities related to money laundering and terrorist financing (Ahmad et al., 2020). Another major challenge relates to the methodological approaches used. Most existing studies rely on average estimation methods, such as ordinary least squares or fixed effects models, which capture only the average effect of ICT on financial inclusion. These approaches mask the differentiated effects along the distribution of financial inclusion and can lead to partial or even biased conclusions in the presence of endogeneity linked to simultaneity, omission of relevant variables, or measurement errors. These limitations are particularly acute in the context of WAEMU countries. Despite the spectacular spread of electronic money, the region continues to face a relatively low level of financial inclusion. In 2021, only 67.2% of adults in the WAEMU had a bank account or e-account, compared with 71% in developing economies as a whole and 76% globally (BCEAO, 2022; Demirgüç-Kunt et al., 2022).

In this context, a key question arises: to what extent do information and communication technologies influence financial inclusion in WAEMU countries, and do these effects vary according to initial levels of financial inclusion? The main objective of this article is to empirically analyze the heterogeneous effects of ICT on financial inclusion in WAEMU countries over the period 2006–2022, explicitly distinguishing between access to financial services and their actual use, and to assess the differentiated role of the main components of ICT. Guided by the theoretical frameworks of innovation diffusion and technology adoption, this study is based on the general hypothesis that ICTs have a positive but uneven effect on financial inclusion. More specifically, we argue that the impact of ICT is more pronounced in countries with low financial inclusion, where it acts as a lever for initial inclusion, than in countries that have already achieved a higher level of inclusion, where it contributes mainly to financial deepening. To test this hypothesis, this study uses the method of moments quantile regression (MMQR) approach developed by Machado and Santos Silva (2019), which allows us to analyze the effects of ICTs along the conditional distribution of financial inclusion while considering endogeneity issues.

This article makes several contributions. First, it draws on a variety of ICT indicators, including mobile telephony, the internet, and fixed telephony, and explicitly distinguishes between two fundamental dimensions of financial inclusion: geographic access and effective use. This approach allows for a more detailed analysis of the underlying mechanisms. Second, the study goes beyond the traditional approach focused on linear relationships and regional averages by using a quantile regression framework based on the MMQR. This approach highlights the heterogeneity of technological effects across the distribution of

financial inclusion, revealing different dynamics between countries with low and high levels of inclusion. It is also suitable for addressing endogeneity issues and controlling for individual fixed effects. Third, by focusing on the WAEMU, a region characterized by widespread use of electronic money and advanced monetary integration, the study provides empirical results that can be directly used to formulate targeted public policies. Finally, for the banking literature, our results shed new light on the relationship between ICT and financial inclusion. They reveal that mobile telephony and the internet are emerging as the main drivers of inclusion in the WAEMU: mobile telephony acts as a lever for catching up in terms of initial use (with a more pronounced effect in the lower quantiles), whereas the internet structures the geographical expansion of digital financial services. Conversely, fixed telephony has no significant effect on financial inclusion. Its role has been limited to improving communication and the internal organization of financial institutions, with no direct impact on the access of excluded populations to financial services, thus illustrating a phenomenon of technological leapfrogging in favor of mobile technologies. Its inability to promote mass financial inclusion can also be explained by high deployment costs, lack of mobility, and low geographic penetration, which make it unsuitable for the realities of rural and informal populations. The robustness of these conclusions is confirmed by the use of the instrumental variables two-stage least squares (IV-2SLS) method.

The rest of the article is structured as follows. Section 2 presents the literature review. Section 3 describes the empirical methodology and data. Section 4 discusses the empirical results, while Section 5 concludes and proposes policy implications.

2. Literature review

2.1. Theoretical foundations: ICT and financial inclusion

The financial sector is particularly sensitive to advances in digital technologies. Theories of financial innovation and banking regulation emphasize the structuring role of technologies in transforming the financial landscape, enabling the emergence of dematerialized, low-cost services accessible via digital channels and contributing to a democratization of access to financial services (Frame & White, 2009; Moufakkir & Qmichchou, 2020; Silber, 1975). The adoption of technologies such as API-based open banking, blockchain, fintech, and Big Tech has promoted financial inclusion while reducing transaction costs (Jameaba, 2024). By integrating these technologies, traditional banks streamlined their processes while offering more personalized and secure services (Komandla & Perumalla, 2017). ICTs thus make it possible to reach previously excluded populations, particularly in rural areas (Saal et al., 2017), and contribute to the achievement of sustainable development goals (Ononiwu et al., 2024; Ozili, 2023). The relationship between ICT and financial inclusion can also be understood through the diffusion of innovations (Rogers, 1962). According to this approach, the diffusion of an innovation depends on its accessibility and its ability to spread throughout the economic space. In the financial sector, the development of ICT contributes to the geographical expansion of financial services by reducing the constraints associated with distance and the organization of distribution networks. This perspective justifies the analysis of financial inclusion through a

spatial dimension, measured by the overall rate of geographical penetration of financial services. However, the geographical expansion of financial services does not necessarily guarantee their effective use. The Technology Acceptance Model (TAM) proposed by Davis (1989) links the availability of technologies to their observed use. This model posits that the adoption of a technology depends on its perceived usefulness and perceived ease of use. At an aggregate level, the development of ICTs is thus likely to increase the use of financial services by improving the efficiency of transactions and reducing access costs. Finally, the digital divide theory developed by van Dijk (2005) emphasizes that structural inequalities in access, skills, and use of ICTs, linked in particular to income, education, gender, and location, determine the benefits derived from digital technology, thus explaining the heterogeneity of its effects on financial inclusion.

2.2. Empirical evidence on the effect of ICTs on financial inclusion

A vast body of empirical literature has sought to explore the causal interactions between ICT adoption and financial inclusion, with a focus on developing economies. In line with this, Kouladoum et al. (2022), using a panel of 42 sub-Saharan African countries over the period of 2004-2020, demonstrated that the joint adoption of mobile telephony and the internet acts as a powerful catalyst for financial inclusion, both on the supply and demand sides of financial services. Similarly, using a fixed-effects panel data regression, Kozol (2026) established that increased use of digital payments is significantly associated with improved financial inclusion in a large sample of countries. Using annual data covering the period 2010-2022, Dianda et al. (2025) employ the method of moments quantile regression (MMQR) approach and show that access to electronic money stimulates financial inclusion through two main channels. First, it facilitates access to formal financial services in previously underserved rural and peri-urban areas by reducing financial and geographical constraints. Second, its impact is more pronounced in countries where the initial level of financial inclusion is already high, suggesting that it acts as a catalyst for populations that are already partially integrated into the formal financial system.

Other studies highlight the importance of ICT infrastructure and the complementarity between different technologies. By studying 12 emerging economies over the period 2010–2024 via random effects models, Shylaja et al. (2025) highlighted the crucial role of digital financial services and ICT infrastructure in strengthening financial inclusion and promoting inclusive economic growth. Similarly, Drama and Senou (2025), using three-stage least squares (3SLS) and seemingly unrelated regression equation (SURE) estimators for 45 sub-Saharan African countries between 2000 and 2023, show that mobile phone penetration promotes financial access through the development of mobile banking, whereas internet diffusion supports the digitization of financial services by reducing costs and distance constraints. These results are consistent with those of Lenka and Barik (2018), who show that the internet improves the use of formal financial services by facilitating access to financial information and strengthening trust in financial institutions. Jain and Sahu (2024) confirmed that the combination of mobile phones and the internet is a key determinant of financial inclusion in emerging economies.

Microeconomic analyses confirm these findings at the household level. Drawing on primary data collected from 733 households in Ghana's administrative region, Amoah et al. (2020) reported that the regular use of mobile payment services to access social and economic services contributes significantly to strengthening financial inclusion, financial empowerment, and the overall well-being of populations.

Despite these widely documented positive effects, the literature highlights the existence of major challenges related to digital finance. Ogunode and Akintoye (2023) reported that in Nigeria, issues such as poor system interoperability, concerns about personal data protection, and the excessive concentration of fintechs in urban areas limit progress in digital financial inclusion. In rural areas, Parvin and Panakaje (2022) highlight the constraining role of low financial literacy and limited technological skills, which hinders the effective use of digital financial services. Issues of trust and security are also significant barriers. Ahmad et al. (2020) highlighted the increased risks of money laundering and terrorist financing associated with the use of electronic money, particularly cryptocurrencies. In Kenya, Gitonga and Wambua (2024) document numerous cases of large-scale fraud involving mobile money, resulting in substantial financial losses, social exclusion, and lasting psychological distress for victims. In Ghana, Odai (2025) reported that mobile money platforms, by making certain transactional information easily accessible, inadvertently increase the attack surface for fraudsters: nearly half of the survey respondents reported being targeted by phishing attempts after a mobile transaction. Finally, Metibemu (2025), combining descriptive statistics, logistic regression, and difference-in-differences analysis, revealed that phishing (35%) and ransomware (20%) are responsible for the largest financial losses, with average losses estimated at \$5.5 million and \$7.1 million per incident, respectively.

3. Empirical analysis methodology

3.1. Econometric model specification

Rogers' seminal work (1962) on the diffusion of innovations provides a relevant theoretical framework for analyzing the expansion of financial services through information and communication technologies (ICTs). According to this approach, the diffusion of an innovation depends on its accessibility and its ability to spread throughout the economic space. In the financial sector, the development of ICT contributes to the geographical expansion of financial services by reducing the constraints associated with distance and the organization of distribution networks. This perspective justifies the analysis of financial inclusion through a spatial dimension, measured by the overall rate of geographical penetration of financial services. However, the geographical expansion of financial services does not necessarily guarantee their effective use. The Technology Acceptance Model (TAM) proposed by Davis (1989) links the availability of technologies to their observed use. This model posits that the adoption of a technology depends on its perceived usefulness and perceived ease of use. At an aggregate level, the development of ICTs is thus likely to increase the use of financial services by improving the efficiency of transactions and reducing access costs. This approach bases the analysis of financial inclusion on the overall rate of use of financial

services. The two dimensions—geographic penetration and effective use of financial services—are thus complementary measures of financial inclusion.

These theoretical foundations imply that financial inclusion results from a process in which the spread of ICTs acts both on the spatial expansion of financial services and on their effective use by economic agents in interaction with macroeconomic and socioeconomic conditions. To translate these theoretical mechanisms into an operational empirical framework, the economic literature uses adoption models that explicitly integrate ICT as a key determinant of financial inclusion. This is the perspective taken by the works of Kpodar and Andrianaivo (2011), Dianda et al. (2025), and Faton and Chabossou (2021), whose models provide an analytical basis for formalizing the relationship between ICT diffusion and financial inclusion. The underlying theoretical relationship can therefore be formalized as follows:

$$FI_{i,t} = F(ICT_{i,t}, X_{i,t}) \quad (1)$$

where FI is the indicator measuring financial inclusion, ICT is the diffusion of ICT, and X is a set of control variables that can explain financial inclusion. Assuming a linear functional relationship, this expression can be approximated by the following specification:

$$FI_{i,t} = \alpha_0 + \alpha_1 ICT_{i,t} + \sum_{k=1}^n X_{i,t}^k + \epsilon_{i,t} \quad (2)$$

For the empirical analysis of the effect of electronic money on financial inclusion in WAEMU countries, our model is inspired by Dianda et al. (2025) and Faton & Chabossou (2021). On the basis of the determinants mentioned in the literature, this model is specified as follows: Financial inclusion = f (macroeconomic instability, socioeconomic factors, ICT) (3)

Thus, the empirical model is written as follows:

$$FI_{i,t} = \beta_0 + \beta_1 INFLA_{i,t} + \beta_2 GDPpc_{i,t} + \beta_3 GPER_{i,t} + \beta_4 NIRBD_{i,t} + \beta_5 UR_{i,t} + \beta_6 ICT_{i,t} + \epsilon_{i,t} \quad (4)$$

where *i* denotes the country and ϵ is the error term;

FI is financial inclusion measured by the degree of access to and use of financial services via two complementary indicators: the overall rate of financial service usage (ORFSU), which includes the use of bank accounts as well as accounts in microfinance institutions and electronic money institutions (BCEAO, 2023), and the overall rate of geographic penetration of financial services (ORGPFs), which expresses the total number of financial service points per 1,000 km². Owing to its high values, ORGPFs has been transformed into a logarithm. These indicators are widely used in the economic literature to reflect the degree of financial inclusion through access to and use of formal financial services (Cámara & Tuesta, 2014; Traore & Diaw, 2020).

The INFLA measures the level of inflation. A low inflation rate is a strong signal of macroeconomic stability. This stability enhances financial inclusion by fostering confidence in the financial system and encouraging formal savings (Čihák et al., 2016). Conversely, high inflation erodes the value of certain financial services, such as savings, thus reducing demand for these services (Abessolo, 2019).

GDPpc is the gross domestic product per capita in country i , measured in purchasing power parity. It is an approximation of the level of individual income. Safoulanitou (2019), Sarma & Pais (2011), and Evans & Adeoye (2016) have shown that an increase in income levels, both at the individual and national levels, can improve the level of financial inclusion.

GPER is the gross primary enrollment rate, an important indicator of individuals' financial behavior at both the microeconomic and macroeconomic levels (B. Ouedraogo, 2008; Sarma & Pais, 2011). According to Ouedraogo (2008), an educated person, compared with an uneducated person, is better informed about the existence of different financial institutions and the opportunities they offer.

NIRBD is the nominal interest rate on bank deposits. This rate measures the return on savings at banks. By paying interest to deposits, an increase in this rate attracts many people to deposit money in commercial banks (Dieme, 2020).

UR is the unemployment rate. Studies show that professional activity promotes access to financial services (Kumar, 2013; Lenka & Barik, 2018), suggesting a negative correlation between this variable and financial inclusion.

ICT: ICT diffusion, measured by the percentage of internet users and the number of fixed and mobile telephone subscribers per 100 inhabitants. Fixed telephony is included in the analysis for comparative purposes to distinguish the impact of traditional telecommunications infrastructure from that of modern digital technologies. The expansion of digital financial services significantly reduces transaction costs and improves access to financial services (Evans & Adeoye, 2016; Lenka & Barik, 2018; Sarma & Pais, 2011; Senou et al., 2019). The expected sign of this variable is positive.

3.2. Data presentation and descriptive analysis

The empirical estimates are based on a panel of data covering the period 2006–2022 for WAEMU countries. The sample includes seven countries, namely, Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, Senegal, and Togo, with Guinea excluded because of missing data for the entire period under review. The data used are secondary in nature and come mainly from the Central Bank of West African States (BCEAO, 2024) for financial inclusion indicators and from the World Bank (WDI, 2024) for ICT indicators and macroeconomic and social control variables.

Table I presents descriptive statistics for the variables used in the analysis, both by country and for the WAEMU as a whole. Over the period studied, the overall rate of use of basic financial services in the WAEMU averaged approximately 42.3%, reflecting a still moderate level of financial inclusion. However, this average masks significant disparities between countries. Benin (58.52%) and Togo (57.45%) have the highest usage rates, whereas Niger (11.18%) and Mali (32.13%) have significantly lower levels. Similarly, the geographical penetration rate of financial services averages 191.26 points at the regional level, with particularly high values in Benin (517.05) and Côte d'Ivoire (238.01), reflecting better territorial coverage of financial services. Conversely, Niger (14.11) and Mali (50.04) are characterized by very low geographic densities of these services, highlighting significant physical access constraints.

The information and communication technology indicators reveal contrasting levels of penetration within the region. Mobile telephony is the most widespread technology, with an average rate of 71.21 subscriptions per 100 inhabitants, but substantial disparities remain between countries. Côte d'Ivoire (100.18) and Senegal (86.39) have the highest levels, whereas Niger (34.13) and Togo (54.71) lag significantly behind. In contrast, fixed telephony remains marginal throughout the WAEMU, with a regional average of approximately 1.01 subscriptions per 100 inhabitants, with only Senegal (2.07) and Côte d'Ivoire (1.14) showing relatively higher levels. Internet access also remains limited, with an average subscription rate of 13.13%. Senegal (24.15%) and Côte d'Ivoire (20.25%) stand out with more advanced coverage, whereas Niger (5.45%) and Burkina Faso (6.85%) are well below the regional average.

Macroeconomic and social variables also show significant disparities between countries. The average unemployment rate in WAEMU is relatively low, at approximately 2.76%, although Burkina Faso (4.26%) and Côte d'Ivoire (4.38%) have rates above the regional average. Conversely, Niger (1.02%) and Benin (1.57%) have the lowest unemployment rates. The gross primary school enrollment rate averages 89.64%, ranging from 66.34% in Niger to 121.82% in Togo, reflecting significant differences in investment in human capital. The average GDP per capita in the WAEMU is estimated at approximately \$2,484, with Côte d'Ivoire (\$4,545) and Senegal (\$3,148) above this average, whereas Niger (\$1,198) and Burkina Faso (\$1,798) have significantly lower income levels. Finally, inflation remained broadly under control over the period, with a regional average of 2.21%, and the nominal interest rate on bank deposits stood at approximately 7.29%, with little variation between countries.

Overall, these descriptive statistics highlight significant heterogeneity among WAEMU countries, both in terms of ICT diffusion and financial inclusion. They suggest that the observed differences in access to and use of financial services may be closely linked to differences in the development of digital infrastructure, particularly mobile telephony and the internet. This heterogeneity motivates the use of quantile regressions in empirical estimates to capture the differentiated effects of ICTs according to different levels of financial inclusion and to explicitly take into account heterogeneous effects between countries.

Table I: Descriptive statistics of the variables used in the estimation (2006–2022)

Variables	2006–2022	Benin	Burkina Faso	Ivory Coast	Mali	Niger	Senegal	Togo	WAEMU
TGUS basic financial services	Mean	58.52	42.74	45.41	32.13	11.18	48.54	57.45	42.28
	Std. Dev.	18.85	25.42	26.36	13.69	6.10	21.78	22.03	24.96
Overall rate of geographic penetration of financial services	Mean	517.05	148.13	238.01	50.04	14.11	207.75	163.79	191.26
	Std. Dev.	843.21	199.25	355.18	70.45	15.66	264.17	218.61	398.69
Mobile phone rate per 100 inhabitants	Mean	73.17	64.57	100.18	85.31	34.13	86.39	54.71	71.21
	Std. Dev.	25.76	34.82	44.08	42.50	17.56	30.72	22.28	37.77
Landline rate	Mean	0.98	0.61	1.14	0.89	0.44	2.07	0.97	1.01

Variables	2006–2022	Benin	Burkina Faso	Ivory Coast	Mali	Niger	Senegal	Togo	WAEMU
	Std. Dev.	0.60	0.25	0.19	0.29	0.17	0.44	0.65	0.63
Internet subscription rate per 100 inhabitants	Mean	11.80	6.85	20.25	11.83	5.45	24.15	11.53	13.12524
	Std. Dev.	10.59	6.00	18.23	11.57	6.38	18.77	11.63	13.95
Unemployment rate	Mean	1.57	4.26	4.38	1.77	1.02	3.71	2.66	2.76
	Std. Dev.	0.53	0.61	2.01	0.66	0.68	1.19	0.72	1.62
Gross primary enrollment rate	Mean	116.12	81.46	81.88	75.52	66.34	84.42	121.82	89.64
	Std. Dev.	8.05	8.66	11.19	3.03	9.04	1.21	5.77	20.79
Gross domestic product per capita	Mean	2786.42	1797.56	4545.75	1991.17	1197.87	3,148.04	1923.14	2484.279
	Std. Dev.	534.77	434.32	1295.20	340.89	226.82	633.31	440.85	1212.80
Level of inflation	Mean	1.92	2.51	2.11	2.25	1.93	2.22	2.56	2.21
	Std. Dev.	2.39	4.19	1.99	3.23	3.03	2.98	2.54	2.912
Nominal interest rate on bank deposits	Mean	6.92	6.94	7.45	7.43	7.43	7.43	7.43	7.287
	Std. Dev.	1.34	1.32	0.69	0.72	0.72	0.72	0.72	0.93

Source: Authors, based on BCEAO data (2024) and the World Bank (WDI, 2024)

3.3. Estimation Strategy

3.3.1. Correlation Matrix

Table II presents the Pearson correlation matrix between the model variables. This highlights a positive and statistically significant correlation between the two measures of financial inclusion, namely, the overall rate of financial service usage (ORFSU) and the geographic penetration rate of financial services (ORGPFs) ($r = 0.650$), suggesting that countries with greater financial service usage also benefit from better geographic coverage of these services.

The information and communication technology indicators show positive and statistically significant correlations with both dimensions of financial inclusion. The overall rate of financial service usage is strongly correlated with mobile telephony ($r = 0.614$) and the internet ($r = 0.515$). Similarly, the geographic penetration rate of financial services is positively associated with mobile telephony ($r = 0.445$) and the internet ($r = 0.575$). These results suggest a close link between ICT development and improved access to and use of financial services, without prejudging a causal relationship. Conversely, fixed telephony shows a nonsignificant correlation with ORFSU and a significant negative correlation with ORGPFS ($r = -0.2605$), reflecting its marginal role in the financial and digital systems of WAEMU countries. Macroeconomic and social variables also show significant associations with financial inclusion. The GDP per capita is positively correlated with both financial inclusion indicators, indicating that higher-income countries tend to have better levels of access to and use of financial services. The gross primary school enrollment rate is also positively associated with financial inclusion, albeit to a lesser extent. In contrast, inflation does not show a statistically significant correlation with financial inclusion indicators. The interest rate on deposits shows a positive and statistically significant correlation with the overall rate of financial service use and with the geographic penetration rate of financial services. This association indicates that, in WAEMU countries, higher deposit rates coincide with greater use of formal financial services and wider geographical coverage of these services, possibly by making bank savings more attractive.

Although the observed correlations between the explanatory variables are weak, a multicollinearity test was performed using the Variance Inflation Factor (VIF). The results presented in Table III indicate that the individual VIFs are below 5 and that the average VIF is 2.25, with tolerance values above the critical threshold of 0.1. These results confirm the absence of problematic multicollinearity in the estimated models (Miles, 2014; Senaviratna & Cooray, 2019).

Overall, the descriptive analysis highlights positive relationships between ICT development and financial inclusion in WAEMU countries. However, these correlations do not establish causal links, which justifies the use of panel econometric estimates to identify the specific effect of ICT on financial inclusion.

Table II: Correlation matrix

Variables	Overall rate of financial service use (ORFSU)	Overall rate of geographic penetration of financial services (ORGPFS)	Mobile phone	Landline	Internet	Unemployment rate	Gross primary enrollment rate (GPER)	GDP per capita	Inflation	Interest rate on deposits
ORFSU	1.000									
ORGPFS	0.650*	1.000								
Mobile phone	0.614*	0.445*	1.0000							
Landline	-0.051	-0.260*	0.093	1.000						
Internet	0.515*	0.575*	0.636*	0.062	1.000					
Unemployment rate	0.116	-0.0602	-0.169*	0.315*	0.014	1.000				
GPER	0.623*	0.271*	0.156*	0.080	0.127	-0.123	1.0000			
GDP per capita	0.605*	0.498*	0.538*	0.233*	0.620*	0.256*	0.1657*	1.000		
Inflation	-0.002	0.061	-0.101	0.051	0.0507	0.027	-0.0324	0.014	1.000	
Interest rate on deposits	0.696*	0.618*	0.545*	0.396*	-0.574*	0.014	0.185*	0.311*	0.094	1.0000

Note: * indicates a statistically significant correlation at the 10% level ($p < 0.10$).

Table III: Multicollinearity test

Independent variables	Overall rate of financial service use		Overall rate of geographic penetration of financial services	
	VIF	1/VIF	VIF	1/VIF
Internet	3.61	0.276992	3.61	0.276992
Mobile phone	3.24	0.308678	3.24	0.308678
GDP per capita	3.21	0.311554	3.21	0.311554
Deposit interest rates	2.64	0.378299	2.64	0.378299
Landline	1.72	0.581945	1.72	0.581945
Unemployment rate	1.35	0.739438	1.35	0.739438
Gross primary enrollment rate	1.15	0.869426	1.15	0.869426
Inflation	1.07	0.938674	1.07	0.938674
Average VIF	2.25		2.25	

Source: Authors, based on BCEAO data (2024) and the World Bank (WDI, 2024)

3.3.2. Tests for autocorrelation and heteroscedasticity of errors

The results of the diagnostic tests presented in Table IV show serial autocorrelation and, in some cases, heteroscedasticity in the residuals. The Wooldridge (2010) test indicates first-order autocorrelation in the panel data. Fisher's statistics are significant for all ICT indicators, with p values often below 5% and 1%. With respect to heteroscedasticity, the results vary depending on the measure of financial inclusion. For the geographic penetration rate of financial services, the Breusch–Pagan (1978) test rejects the null hypothesis of homoscedasticity for all ICT indicators. The chi-square statistics are highly significant (Prob > $\chi^2 = 0.0000$), indicating nonconstant residual variance. In contrast, for the overall rate of financial service usage (ORFSU), the test p values are largely insignificant. The homoscedasticity hypothesis cannot therefore be rejected. The variance of the residuals is therefore statistically constant. These results show that, depending on the model specification, the residuals may exhibit correlation over time and/or nonconstant variance. It is therefore essential to take these characteristics into account to ensure the reliability of statistical inferences.

Table IV: Diagnostic test for heteroskedasticity and autocorrelation

	Heteroskedasticity (probability)		Serial correlation (probability)	
	Overall rate of geographic penetration of financial services	Overall rate of financial service use (ORFSU)	Overall rate of geographic penetration of financial services	Overall rate of financial service use
Mobile phone	chi2(1) = 174.51 Prob > chi2 = 0.0000	chi2(1) = 0.07 Prob > chi2 = 0.7942	F(1, 6) = 8.295 Prob > F = 0.0281	F(1, 6) = 41.829 Prob > F = 0.0006
Landline	chi2(1) = 176.06 Prob > chi2 = 0.0000	chi2(1) = 1.26 Prob > chi2 = 0.2608	F(1, 6) = 8.439 Prob > F = 0.0272	F(1, 6) = 53.257 Prob > F = 0.0003
Internet	chi2(1) = 160.22 Prob > chi2 = 0.0000	chi2(1) = 0.47 Prob > chi2 = 0.4942	F(1, 6) = 8.286 Prob > F = 0.0281	F(1, 6) = 57.905 Prob > F = 0.0003

Source: Authors, based on BCEAO data (2024) and the World Bank (WDI, 2024)

3.3.3. Choice of estimation method

The analysis of the effects of ICTs, particularly mobile telephony, the internet, and fixed telephony, on financial inclusion is likely affected by endogeneity issues in the panel data used. Three main sources can be identified: omission of relevant variables, simultaneity of

the relationship, and measurement errors. The omission of variables results from the fact that, despite the inclusion of several explanatory variables, certain unobserved dimensions that may influence financial inclusion may not be taken into account. On the other hand, the bidirectional nature of the relationship between ICT and financial inclusion is reflected: on the one hand, the spread of ICT facilitates access to, use of, and quality of financial services; on the other hand, increased demand for financial services may encourage providers to develop digital infrastructure and digital financial services, thus generating reverse causality (Chatterjee, 2020). Furthermore, macroeconomic data are inherently subject to measurement errors (Dianda, Thiombiano, et al., 2025). These various mechanisms render the ICT variable endogenous and invalidate the use of the Ordinary Least Squares (OLS) method, especially since the presence of heteroscedasticity and autocorrelation has been proven. Additionally, descriptive statistics reveal significant heterogeneity among WAEMU countries regarding both ICT diffusion and financial inclusion. Since the impact of ICTs is not uniform across the distribution of the indicators considered, the use of quantile regression is particularly relevant to capture these differentiated effects and to explicitly account for country-specific heterogeneity.

In this context, we adopt the Method of Moments Quantile Regression (MMQR) approach proposed by Machado and Santos Silva (2019). This framework allows for an analysis of the entire conditional distribution of the dependent variable by estimating coefficients specific to different quantiles, without relying on strict parametric assumptions regarding error distribution (Ayed, 2017; D'Haultfoeuille & Givord, 2014). While the traditional quantile regression developed by Koenker and Bassett (1978) is recognized for its robustness to outliers and heteroscedasticity, the MMQR method offers the major advantage of allowing for the inclusion of individual fixed effects within a panel framework while effectively managing unobserved heterogeneity (Cameron & Trivedi, 2005; Koenker, 2004).

The choice of MMQR is also crucial for the reliability of estimates in the face of potential model misspecification. As highlighted by recent work on the asymptotic properties of Generalized Method of Moments (Kang et al., 2025), quantile regression methods based on non-smooth moment conditions may see their convergence rate slow from \sqrt{n} to $n^{1/3}$ if the model is misspecified. Conversely, the MMQR approach, by utilizing moment conditions that remain directionally differentiable, preserves a robust convergence rate of \sqrt{n} . This property ensures greater precision in the results and allows for a nuanced understanding of how ICTs influence financial inclusion across different levels of development.

The principle of MMQR is to estimate conditional quantiles by combining estimates of location and scale functions. The conditional location scale model is given by:

$$Y = X'\beta + \sigma(X'\gamma)U, \quad (5)$$

where Y is the scalar outcome variable, X includes the endogenous variable D and other exogenous covariates, and $\sigma(\cdot)$ is a known function.

On the basis of normalization of the unobserved random variable U , Machado and Santos Silva (2019) use the moment conditions $E[ZU] = 0$ and $E[Z(|U|-1)] = 0$ with instrument Z to obtain consistent estimates of β and γ under very general conditions by applying the GMM.

Given the estimates of β and γ , $q(\tau)$ can be estimated via the following moment condition:

$$E \left[\tau - 1 \left(\frac{Y - X'\beta}{\sigma(X'\gamma)} \leq q(\tau) \right) \right] = 0 \quad (6)$$

where traditional quantile regression can be applied to the estimated residuals. By combining $\hat{\beta}$, $\hat{\gamma}$, and $\hat{q}(\tau)$, estimates of the desired regression quantile coefficient can be obtained. $q(\tau)$ represents the estimated conditional quantile of the dependent variable at the specified quantile level τ .

Estimates are performed in Stata via the `ivqreg2` command. In accordance with the recommendations of Machado and Santos Silva (2019), we use all the exogenous variables in the model as instruments, as well as the geographical penetration rates and demographics of electronic money services individually according to 1. The MMQR estimates are performed via Stata software via the `ivqreg2` command. In accordance with the recommendations of Machado and Santos Silva (2019), all exogenous variables in the model

are retained as instruments, to which are added, according to the estimated specifications, mobile phones, landline phones, and the internet.

To assess the robustness of the results obtained from the MMQR, we also use the instrumental variables two-stage least squares (IV-2SLS) method. This alternative approach allows us to simultaneously correct for endogeneity bias, autocorrelation, and heteroscedasticity. The instruments used correspond to the values of ICT-related variables delayed by two periods, a strategy widely adopted in the empirical literature (Bouhari, 2023; et al., 2025; Li et al., 2023). The choice of a two-period lag is justified by several considerations. On the one hand, it mitigates simultaneity by breaking the bidirectional causality between ICT and financial inclusion; on the other hand, it limits the influence of transitory shocks while preserving the relevance of the instruments, given the gradual nature of digital technology adoption. According to Wooldridge (2016), the validity of instruments depends on two essential conditions: relevance, which requires a significant correlation between instruments and endogenous variables, and exogeneity, which requires no correlation between instruments and the error term. To verify these conditions, we systematically perform Sargan's overidentification test after each estimation. A nonsignificant Sargan test provides empirical support for the validity of the instruments selected.

4. Main Results and Discussion

This section presents the empirical findings obtained using the Method of Moments Quantile Regression (MMQR) approach developed by Machado and Santos Silva (2019). To ensure the validity of our findings, we also present robustness checks conducted via the Instrumental Variables Two-Stage Least Squares (IV-2SLS) method.

4.1. Estimation results via MMQR by Machado and Santos Silva (2019)

Tables V and VI report the results of the MMQR estimations regarding the impact of Information and Communication Technologies (ICTs) on financial inclusion in WAEMU countries. Financial inclusion is measured through two complementary dimensions: the use of financial services (overall rate of financial service use) and the geographical accessibility of financial services (overall rate of geographic penetration of financial services). The results highlight a high degree of heterogeneity in the effects of ICT, confirming that their impact varies according to the initial level of financial inclusion in each country.

With respect to the use of financial services, estimates show that the effects of mobile telephony and the internet are consistently positive, but their intensity varies according to the maturity of use in each country (Table V). For mobile telephony, the coefficients are positive and statistically significant at the 0.10, 0.50, and 0.90 quantiles, but their magnitude gradually decreases as we move from the lower quantiles to the higher quantiles. These results indicate that mobile telephony has a more pronounced effect in countries characterized by low initial use of financial services, whereas its marginal effect diminishes as the level of financial inclusion increases. In countries characterized by low use of financial services (lower quantiles), the spread of mobile telephony helps to remove major constraints on the demand side, including distance from formal financial institutions, high transaction costs, and administrative and informational barriers. Through services such as electronic money, mobile payments, and local savings, mobile telephony facilitates entry into the financial system for previously excluded populations.

Conversely, the internet shows positive and statistically significant coefficients across all quantiles considered, with relatively limited variation in their magnitude along the distribution. This stability indicates that the internet acts as a cross-cutting and structuring infrastructure, supporting the use of financial services in a relatively homogeneous manner, regardless of the initial level of financial inclusion. Unlike mobile telephony, the internet does not merely facilitate initial access to financial services. It also promotes the diversification of digital financial services, the development of online banking and fintech platforms, and improved financial information and user confidence. Thus, the internet contributes to both financial inclusion and financial deepening by increasing the intensity

and sophistication of financial service use, even in countries where inclusion is already relatively advanced.

With respect to the geographical penetration of financial services, the results (Table VI) also highlight marked heterogeneity in the effects along the distribution. The coefficients associated with mobile telephony are positive and significant across all quantiles but increase gradually from the 0.10 quantile to the 0.90 quantile. This indicates that the expansion of mobile networks is not limited to extending financial services to areas that were initially underserved but contributes even more significantly to the densification of financial services, particularly through the proliferation of electronic money service points, the expansion of financial agent networks, and the reduction in fixed costs associated with opening traditional bank branches in countries where geographic penetration is already relatively high. Mobile telephony thus acts as an effective substitute for physical banking infrastructure, strengthening the capillarity of the financial system. Similarly, the internet has positive and significant effects across all quantiles but with a gradual decrease in the magnitude of the coefficients as we move along the distribution. This suggests that the internet plays a particularly important role in the initial phases of the geographical expansion of financial services. In countries with few financial service outlets, the internet facilitates the establishment of digital platforms, the remote management of financial transactions, and the coordination of networks of agents and financial institutions. As geographic coverage becomes denser, its marginal effect diminishes, with the internet becoming more of a tool for consolidation than for spatial expansion.

Overall, these results highlight that ICTs play a dual role in WAEMU countries. On the one hand, they constitute a basic financial inclusion mechanism, facilitating initial access to formal financial services for previously excluded populations. The spread of mobile telephony and the internet makes it possible to circumvent the shortcomings of traditional financial infrastructures by reducing the geographical constraints associated with the remoteness of financial institutions, the physical constraints associated with the sparse banking network, and the informational constraints resulting from information asymmetries and low levels of financial education. On the other hand, digital ICTs also act as a factor in deepening the financial system by promoting more intensive, diversified, and sophisticated use of financial services. They support the development of digital financial services, the rise of fintech platforms, the improvement of financial information quality, and user confidence, thereby helping to strengthen the capillarity and efficiency of the financial system. This dual effect of inclusion and deepening explains why the impact of ICT is not limited to countries with low inclusion but is also observed in economies where financial inclusion is already relatively advanced. These results are in line with several studies in the economic literature, notably those by Shylaja et al. (2025), Drama and Senou (2025), Jain and Sahu (2024), Senou et al. (2019), and Dianda et al. (2025), which also show that mobile phones, the internet, and, more generally, digital financial services promote financial inclusion by making financial services more accessible and simultaneously addressing barriers on both the demand and supply sides. These findings are also consistent with statistics from the BCEAO (2023), according to which, in 2022, 98.8% of financial service outlets were electronic money outlets, with a usage rate of 56.6%, compared with 22.0% for microfinance services and 21.0% for banking services.

Contrary to our initial expectations, the results show that fixed telephony has no statistically significant effect on financial inclusion, regardless of the indicator used and the quantile considered. The lack of a significant effect of this technology can be explained by several factors. First, while fixed telephony has historically contributed to the modernization of formal financial systems, particularly by facilitating internal communications within banking institutions, its role in promoting financial inclusion has remained structurally limited. In the contemporary dynamics of financial inclusion, this technology now appears obsolete and no longer plays a significant operational role in the mechanisms for accessing and using financial services in WAEMU countries. Faced with the rise of mobile digital technologies, fixed telephony no longer meets the requirements of flexibility, accessibility, and speed that characterize modern financial systems, particularly in contexts marked by a high geographical dispersion of populations and a high prevalence of informality. Second,

the very low penetration of fixed telephony automatically reduces its potential macroeconomic impact. According to data from the West African Economic and Monetary Union (UEMOA, 2020), the average penetration rate of fixed telephony is less than 1% (approximately 0.45%) because of the high costs of deploying and maintaining wired infrastructure, combined with a low rate of household electrification, particularly in rural areas. In this context, fixed telephony is neither a channel for the mass dissemination of financial information nor an infrastructure suited to the development of digital financial services. Third, the technological trajectory of WAEMU countries is characterized by a direct increase in mobile telephony, a phenomenon commonly referred to as technological leapfrogging. Mobile phone subscription rates reach approximately 94% in the region (Lokossi, 2023), reflecting the almost complete replacement of fixed telephony by mobile technologies, which are more flexible, less costly to deploy, and better suited to local geographical and socioeconomic constraints (Chabossou, 2015; Hamilton, 2003). This substitution is all the more pronounced given that digital financial services, particularly electronic money, rely almost exclusively on mobile networks, making fixed telephony largely marginal in the financial inclusion value chain. Finally, this dynamic is reinforced by the focus of public policy and private investment in the ICT sector, which has largely favored the development of mobile telephony and, more recently, mobile internet, which are perceived as more direct and effective levers for expanding access to information, reducing transaction costs, and promoting financial inclusion.

With respect to the control variables, the school enrollment rate is positively and significantly associated with both indicators of financial inclusion (Tables V and VI), particularly in countries where financial inclusion is lowest (10% and 50% quantiles). This highlights the central role of human capital in understanding, adopting, and using formal financial services. Indeed, an educated person is more likely to be informed about financial institutions and their offerings, to understand procedures and operating principles, to assess benefits, and to make informed decisions about their financial transactions. These findings are largely corroborated by the literature (Haoudi & Rabhi, 2018; Ouedraogo, 2008; Sarma & Pais, 2011). The GDP per capita has a positive but relatively moderate effect. Its impact is more robust in the high quantiles of financial inclusion, suggesting that increasing average income contributes more to deepening than to initial access to financial services. These results show that an increase in average income leads to demand for banking services, particularly bank accounts, which offer a safe and convenient way to save and manage savings. Our results are consistent with those of Sharif et al. (2022) and Benyacoub and Azirar (2021), who reported that increasing levels of education promote financial inclusion. The results relating to the unemployment rate highlight negative and statistically significant effects only at certain quantiles of the financial inclusion distribution. This heterogeneity suggests that the deterioration in labor market conditions affects the use of financial services in countries characterized by low or intermediate levels of financial inclusion. In these contexts, the prevalence of unemployment reduces income stability and increases economic uncertainty for households, limiting their ability to access formal financial services and use them on a regular basis. In contrast, in countries in the upper quantiles, where financial systems are more developed and social safety nets are relatively more effective, the marginal impact of unemployment on financial inclusion tends to be mitigated. This interpretation is consistent with the work of Lenka & Barik (2018), Kumar (2013), and Hess et al. (2021), who have shown that access to and effective use of financial services are closely linked to labor market participation and income stability. Similarly, Asongu and Odhiambo (2025) highlighted that employment shocks disproportionately affect populations that are poorly integrated into the financial system, thereby reinforcing inequalities in inclusion. Furthermore, deposit interest rates appear to be positively and significantly associated with financial inclusion across all quantiles considered. This result reflects an incentive effect to open accounts and hold formal savings, reinforcing the attractiveness of the formal financial system over informal value storage mechanisms. Higher interest rates on deposits encourage households to enter the banking system to secure their savings and improve their real returns. This positive relationship is in line with Dieme's analyses (2020), which show that deposit interest rates are a key determinant of bank account use in low-income countries.

Table V: Effect of ICT on the overall rate of financial service use

Variables	Dependent variable: Overall rate of financial service use								
	Mobile phone (Q= 0.10)	Mobile phone (Q=0.50)	Mobile phone (Q=0.90)	Internet (Q=0.10)	Internet (Q=0.50)	Internet (Q=0.90)	Landline (Q=0.10)	Landline (Q=0.50)	Landline telephone (Q=0.90)
ICT variables	0.233*** (0.040)	0.195*** (0.061)	0.143*** (0.142)	0.692** (0.348)	0.624*** (0.097)	0.586*** (0.099)	1.764 (4.206)	0.047 (2.098)	1.567 (3.890)
Unemployment rate	-1.973* (1.006)	-1.400 (0.996)	-0.603 (2.627)	2.780 (1.872)	-2.244*** (0.742)	-1.945*** (0.728)	-1.723 (1.450)	-1.400 (0.917)	1.095 (1.749)
Gross primary enrollment rate	0.623*** (0.049)	0.589*** (0.046)	0.541*** (0.086)	0.658*** (0.076)	0.608*** (0.035)	0.579*** (0.036)	0.628*** (0.066)	0.582*** (0.045)	0.539*** (0.058)
GDP per capita (PPP)	0.002 (0.002)	0.003** (0.002)	0.005 (0.004)	0.002 (0.004)	0.002** (0.001)	0.003*** (0.001)	0.007*** (0.002)	0.007*** (0.001)	0.007*** (0.002)
Inflation	-0.535 (0.704)	-0.650* (0.337)	-0.811 (0.586)	0-.087 (0.826)	0.219 (0.302)	0.292 (0.257)	0.174 (0.705)	0.506 (0.360)	0.818 (0.597)
Deposit interest rates	10.115*** (2.594)	10.781*** (1.308)	11.707*** (3.531)	8.459** (4.085)	9.966*** (1.448)	10.809*** (1.112)	11.555*** (3.732)	13.567*** (1.818)	15.459*** (3.013)
Constant	21.817 (15.867)	40.475*** (12.656)	66.455* (36.733)	12.671 (25.788)	40.582*** (10.730)	56.189*** (11.409)	39.097 (26.026)	67.381*** (15.117)	93.970*** (29.276)
Observations	119	119	119	119	119	119	119	119	119

Source: Authors, based on BCEAO data (2024) and the World Bank (WDI, 2024)

Note: Values in parentheses represent standard errors, whereas ***, **, and * indicate the significance of coefficients at the 1%, 5%, and 10% levels, respectively.

Table VI: Effect of ICT on the overall rate of geographic penetration of financial services

Variables	Dependent variable: Overall rate of geographic penetration of financial services								
	Mobile phone (Q= 0.10)	Mobile phone (Q=0.50)	Mobile phone (Q=0.90)	Internet (Q=0.10)	Internet (Q=0.50)	Internet (Q=0.90)	Landline (Q=0.10)	Landline (Q=0.50)	Landline telephone (Q=0.90)
ICT variable	0.016*** (0.003)	0.021*** (0.006)	0.025** (0.011)	0.079*** (0.012)	0.066*** (0.007)	0.056*** (0.010)	0.479 (0.413)	0.533 (0.172)	0.575 (0.187)
Unemployment rate	-0.090 (0.057)	0.076 (0.062)	0.063 (0.125)	-0.240*** (0.084)	-0.170*** (0.043)	0.110 (0.051)	0.009 (0.111)	-0.035 (0.059)	-0.055 (0.084)
Gross primary enrollment rate	0.036*** (0.005)	0.032*** (0.004)	0.028*** (0.005)	0.049*** (0.005)	0.034*** (0.003)	0.021*** (0.004)	0.034*** (0.009)	0.029*** (0.004)	0.024*** (0.005)
GDP/capita (PPP)	0.0004*** (0.0001)	0.0002 (0.0001)	0.0000 (0.0003)	-0.0000 (0.0002)	0.0001 (0.0001)	0.0003*** (0.0001)	0.0007*** (0.0002)	0.0005*** (0.0001)	0.0005*** (0.0001)
Inflation	-0.015 (0.037)	0.010 (0.027)	0.034 (0.034)	-0.011 (0.054)	-0.036 (0.023)	-0.058*** (0.018)	-0.035 (0.054)	-0.010 (0.030)	0.009 (0.041)
Deposit interest rates	1.349*** (0.100)	1.304*** (0.127)	1.261*** (0.224)	1.258*** (0.114)	1.201*** (0.072)	1.152*** (0.107)	1.697*** (0.231)	1.778*** (0.125)	1.839*** (0.218)
Constant	6.566*** (1.051)	7.714*** (1.158)	8.798*** (1.879)	5.431*** (1.171)	7.468*** (0.656)	9.212*** (0.821)	9.247*** (2.446)	11.819*** (1.092)	13.758*** (1.601)
Observations	119	119	119	119	119	119	119	119	119

Source: Authors, based on BCEAO data (2024) and the World Bank (WDI, 2024)

Note: Values in parentheses represent standard errors, whereas ***, **, and * indicate the significance of coefficients at the 1%, 5%, and 10% levels, respectively

4.2. Robustness of results

To assess the robustness of our MMQR results, we also estimate the model using the instrumental variables two-stage least squares (IV-2SLS) method. Table VII presents the estimates obtained via this method. Sargan tests ($p > 0.10$) confirm the validity of the instruments used in these models. The results from the IV-2SLS estimation with fixed effects confirm the conclusions of the MMQR. The coefficients associated with mobile telephony and the internet remain positive and significant for both dimensions of financial inclusion, whereas fixed telephony remains insignificant. The convergence of results between the MMQR and IV-2SLS reinforces the credibility of the hypothesis that the spread of digital ICTs is a major determinant of financial inclusion in WAEMU countries.

Table VII: IV-2SLS estimation results

Variables	Dependent variable: Overall rate of financial service use			Dependent variable: Overall rate of geographic penetration of financial services		
Mobile phone	0.210*** (0.046)			0.015*** (0.004)		
Internet		0.674*** (0.099)			0.063*** (0.008)	
Landline			0.245 (2.001)			0.600 (0.166)
Unemployment rate	-1.799*** (0.516)	-2.936*** (0.484)	-2.024*** (0.596)	-0.087* (0.048)	-0.188*** (0.041)	0.045 (0.049)
Gross primary enrollment rate	0.618*** (0.040)	0.629*** (0.037)	0.587*** (0.044)	0.027*** (0.004)	0.029*** (0.003)	0.023*** (0.004)
GDP/capita	0.003*** (0.001)	0.002* (0.001)	0.007*** (0.001)	0.0003*** (0.0001)	0.0001 (0.0001)	0.0005*** (0.0001)
Inflation	0.743*** (0.268)	0.198 (0.240)	0.462 (0.286)	-0.003 (0.025)	-0.049** (0.020)	-0.019 (0.024)
Interest rate	10.504*** (1.010)	9.243*** (0.951)	13.049*** (1.158)	1.343*** (0.094)	1.173*** (0.080)	1.726*** (0.096)
Constant	34.235*** (10.001)	32.153*** (8.511)	61.930*** (10.051)	8.644*** (0.927)	7.885*** (0.715)	12.046*** (0.835)
Observations	109	109	109	109	109	109
Wald Chi2	865.91	1068.68	703.95	778.20	1184.32	807.48
R ² (overall)	0.898	0.916	0.878	0.888	0.924	0.892
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sargan J statistics	3.45	5.79	0.80	5.17	2.62	0.01
Sargan J p value	0.631	0.161	0.3716	0.230	0.1055	0.9064

Source: Author, based on BCEAO data (2023) and the World Bank (WDI, 2023)

Note: Values in parentheses represent standard errors, whereas ***, **, and * indicate the significance of coefficients at the 1%, 5%, and 10% levels, respectively.

Conclusion and policy implications

This study analyzed the heterogeneous effects of Information and Communication Technologies (ICTs) on financial inclusion in WAEMU countries from 2006 to 2022. By moving beyond traditional mean-based regression analyses, the application of the Method of Moments Quantile Regression (MMQR) allows for capturing the complexity of this relationship across the entire distribution of financial inclusion. Furthermore, this approach effectively addresses issues of endogeneity and structural heterogeneity inherent to the region. The results of this research can be summarized in three key points. First, our results confirm that mobile telephony and the internet are real drivers of digital finance at WAEMU. However, their influence differs depending on the initial level of inclusion: mobile telephony acts as a powerful lever for catching up in the use of financial services (an effect that is more pronounced in the lower quantiles). Conversely, the internet plays a predominant structural role in the geographical expansion of supply, promoting the digitization of distribution networks. Second, the study highlights the obsolescence of fixed telephony as a tool for mass inclusion. Although it has improved communication and internal coordination within financial institutions, its high cost and lack of mobility make it unsuitable for the realities of rural and informal populations in the Union. Finally, the analysis emphasized that technological development alone is not enough. Financial inclusion remains dependent on key contextual variables: human capital (education) and macroeconomic stability (inflation control) remain essential prerequisites for populations not only to access digital tools but also to use them in a sustainable and secure manner. The robustness of our results is confirmed by the instrumental variables two-stage least squares (IV-2SLS) method with robust standard errors, thereby reinforcing the credibility of our conclusions.

On the basis of these findings, economic policy recommendations should prioritize the development of mobile infrastructure and internet connectivity. It is imperative for WAEMU policymakers to promote the expansion of network coverage (4G/5G) and reduce the cost of mobile internet access, as these two technologies are the real drivers of inclusion for the most vulnerable populations. At the same time, the BCEAO and governments must encourage the development of financial services specifically designed for mobile interfaces (USSD and applications) while encouraging traditional banking institutions to fully integrate their systems with e-wallets. The success of these measures also depends on massive investment in digital literacy so that the ubiquity of mobile phones can be transformed into a real ability to manage complex financial services. Finally, securing transactions carried out via the internet and mobile phones is crucial to maintaining user confidence and limiting the risk of cybercrime. Although this research provides new insights, it has limitations that open up exciting prospects for future work. First, the analysis focused on the WAEMU zone, which limits the generalizability of the results to regions that do not share the same monetary integration. Interregional comparative studies could help identify how different regulatory frameworks influence the effectiveness of ICTs. Second, the use of aggregate data does not allow for the observation of microeconomic disparities. Future research would benefit from using household survey data to analyze how mobile and internet technologies specifically affect women, young people, and

rural populations. Finally, given the rise in cybercrime linked to mobile finance, incorporating qualitative dimensions related to perceptions of security would be relevant. Exploring these mechanisms would enable even more targeted recommendations to be made to protect consumers in the digital finance ecosystem.

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