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Information and communication technologies, financial inclusion and economic growth: evidence from high- and low-income countries

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Abstract

Purpose – This study aims to assess the impact of information and communication technologies (ICT) and financial inclusion on economic growth. This study also examines whether ICT can be a determinant of financial inclusion. Moreover, this study provides new evidence concerning whether ICT can reduce the financial inclusion gap.

Design/methodology/approach – This study uses the country-level data over the period 2005–2019 and estimate using the dynamic and the static panel model.

Findings – The results show that the ICT and financial inclusion interaction variable substantially and positively impacts economic growth for only certain interaction variables. ICT is an essential determinant of financial inclusion and reduces some gaps.

Originality/value – This study contributes to the literature by considering whether ICT and financial inclusion impact economic growth in high- and low-income countries. The other contribution of this study is that ICT represents a determinant in promoting financial inclusion. The final contribution of this study is providing new evidence concerning whether ICT can reduce the financial inclusion gap so that financial access can increase, financial inclusion can develop and simultaneously encourage economic growth.

Keywords ICT, Financial inclusion, Economic growth, High- and low-income countries

Paper type Research paper

1. Introduction and motivation

The advent of information and communication technologies (ICT) has revolutionized various sectors, notably the financial sector, by facilitating access to financial services for previously excluded populations. This technological advancement is particularly impactful in developing regions where traditional banking infrastructure is limited. Mobile broadband and internet technologies have emerged as pivotal tools in enhancing financial inclusion, offering platforms for digital transactions, savings and credit facilities. These services are crucial for integrating unbanked populations into the formal financial system, thereby fostering economic growth through increased investment, consumption and productivity.

Although numerous studies have explored the impact of ICT on economic growth using various methodological approaches and cross-country panel data (Bahrini and Qaffas, 2019; Choi and Hoon Yi, 2009; Datta and Agarwal, 2004; Latif *et al.*, 2018; Lee *et al.*, 2012;

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Pohjola, 2000; Vu, 2011), few have treated financial inclusion as an intervening variable in this relationship. While the positive relationship between ICT and economic growth is well-established (e.g. Bahrini and Qaffas, 2019), the precise mechanism through which ICT fosters growth remains a topic of ongoing investigation. This study addresses a critical gap in the existing literature by examining the differential impact of ICT and financial inclusion (FI) on economic growth across high- and low-income countries using dynamic linear panel models. Furthermore, it investigates the impact of ICT on FI and the FI gap, hypothesizing that ICT significantly reduces this gap.

Unlike previous studies that primarily focus on the direct effects of ICT on economic growth, often overlooking the crucial role of FI as a mediating variable, this study delves deeper to investigate how ICT can bridge the FI gap, ultimately boosting economic growth. We further differentiate our approach by analyzing the impact of ICT and FI in both high- and low-income settings, acknowledging the potential for distinct economic dynamics in each. Notably, existing research offers mixed results regarding the influence of ICT and FI on economic growth in developing economies (e.g. Chatterjee, 2020).

This study uses dynamic linear panel models aligned with the endogenous growth framework (e.g. Andrianaivo and Kpodar, 2011). This approach allows us to capture the lagged effects of ICT and FI on economic growth, providing a more comprehensive understanding of their long-term influence. We further explore the interaction effects between ICT and FI variables, revealing how their combined influence on economic growth may differ across income levels. By addressing these research gaps and using a robust methodological framework, this study offers valuable new insights into the complex relationship between ICT, FI and economic growth. This methodological approach allows us to capture the lagged effects of ICT and FI on economic growth, providing a comprehensive understanding of their long-term impacts. We further explore the interaction effects between ICT and FI variables, aiming to reveal how their combined influence on economic growth varies across different income levels.

By addressing the critical research gaps identified in the existing literature, our study offers valuable new insights into the complex relationship between ICT, FI and economic growth. Our findings have significant implications for policymakers and financial institutions, highlighting the potential of ICT to enhance FI and drive sustainable economic development. The study's novel approach to examining the differential impacts of ICT and FI across high- and low-income countries provides a deeper understanding of the economic dynamics at play, offering a valuable contribution to the literature. By providing a comprehensive analysis of the interplay between ICT, FI and economic growth, our study offers a solid foundation for future research and policy initiatives aimed at fostering inclusive and sustainable economic development.

The rest of the paper is organized as follows. Section 2 reviews the literature. Section 3 explains the data, the empirical model and the econometric methodology. Section 4 presents empirical results. Section 5 concludes the study and lists its limitations, policy implications and the future scope of research.

2. Literature review

2.1 ICT and economic growth

One of the first economic growth models suggesting the importance of technology as input for economic growth was the neoclassical growth theory developed by Solow. Other early economic growth models include the Ramsey–Cass–Koopman and Diamond models, which resemble the Solow Model but determine the dynamic of economic aggregates at the microeconomic level (Romer, 2019). The following economic growth models utilized endogenous growth theory. For Romer (2012), endogenous economic growth assumes production functions more broadly, with workforce and capital combining to develop the technology.

ICT is a part of technologies, and previous studies have defined ICT in various ways as a sector (OECD, 2002), as a composite index (Samimi *et al.*, 2015) and as a tool (Azril *et al.*, 2012). As a product of the industrial telecommunication sector, ICT products represent network externalities. According to Economides and Himmelberg (1994), product value deriving from industrial telecommunications corresponds to network externalities dependent on how many consumers purchase a similar product, with critical mass usually characterizing products featuring network externalities. The researchers described the critical mass as representing an equilibrium market for a product characterized by the installed base expanding beyond a certain minimum level (Economides and Himmelberg, 1994).

2.2 ICT, financial inclusion and economic growth

Andrianaivo and Kpodar (2011) state that two transmission channels from ICT for economic growth. First, from the supply side, ICT directly contributes to domestic output and employment creation, increases government revenues and affects balance payments. Second, from ICT use, ICT indirectly spurs capital accumulation, improves a firm's productivity, creates a better and more extensive market, deepens FI and contributes to rural development. According to Chatterjee (2020), the increasing use of ICT has promoted the appearance of branchless banking, expected to better FI. Meanwhile, according to the World Bank (2018), FI describes businesses and individuals having access to valuable and affordable financial products and services that meet their needs – including payments, credits, savings and insurance – delivered responsibly and sustainably.

From a theoretical perspective, FI can drive economic growth, with Schumpeter's (1983) theoretical approach suggesting that FI encourages economic growth. Building on that theory, Bakar and Sulong (2018) has explained that the financial sector facilitates access to capital and develops innovation, efficiency and investment, driving economic growth.

ICT benefits the financial sector by facilitating access to high-quality financial products and services. Modern society demands that everybody has financial access to a mobile phone or the internet, especially those living in remote areas. According to the World Bank (2018), accessing digital financial services represents the first step to developing FI because a transaction account allows people to send and receive payments and store money.

However, the United Nations (2019) states that many developing countries need help using the digital economy. For instance, African countries contend with problems on the digital economy's demand side, including public trust, the limited capacity of digital technology, outdated or weak technology and low levels of internet bandwidth. There is a significant gap between countries in the connectivity dimension of the digital economy use correlated with income level, education, gender and geography.

To conclude, ICT has several channels to affect economic growth, and FI is one. Moreover, countries with different economies may have different conditions for digital technology. It is interesting to investigate the effect of ICT on economic growth via FI channels in each group of countries.

3. Data and methodology

3.1 Data

We explored the contextual nexus between various ICT and FI indicators of 190 countries divided into high- and low-income country groups [1]. This study uses secondary data from the World Bank, the International Telecommunication Union (ITU) and the International Monetary Fund (IMF). Table 1 presents a data description of all variables considered in this study and source.

Table 1. Data definition and source

Variables	Definition	Source
$y_{i,t}$	Gross domestic product (GDP) per capita (constant 2010 USD)	World Development Indicators (World Bank, 2020c)
$y_{i,t-1}$	Gross domestic product (GDP) per capita (constant 2010 USD), $t-1$	World Development Indicators (World Bank, 2020c)
$ICT_{i,t}$	Information and communication technologies are measured from mobile broadband subscriptions per 100 inhabitants and the percentage of the population using the internet	ICT Statistics (International Telecommunication Union, 2021)
$FI_{i,t}$	Financial inclusion is measured from deposit accounts with commercial banks per 1.000 adults, outstanding loans from commercial banks per 1.000 adults, number of ATMs per 100.000 adults, number of commercial bank branches per 1.000 km^2, number of commercial bank branches per 100.000 adults, number of mobile money transactions (during the reference year) per 1,000 adults	Financial Access Survey (International Monetary Fund, 2021)
Gap $FI_{i,t}$	Gap financial inclusion is measured from a gender gap, education gap and economic status gap on financial institution account, borrowed from a financial institution, made or received digital payments in the past year	The Global Findex Database (World Bank, 2020b)
$X_{i,t}$	Human resource is measured from education (secondary school-enrolment rate) and workforce (employment to population ratio)	Education Statistics (World Bank, 2020a) World Development Indicators (World Bank, 2020c)
	Trade openness is measured by the number of exports and imports in proportion to GDP (%)	World Development Indicators (World Bank, 2020c)
	Value-added of industry (% of GDP) and value-added of services (% of GDP)	World Development Indicators (World Bank, 2020c)
	Investment is measured by foreign direct investment (FDI)	World Development Indicators (World Bank, 2020c)
	Population density is measured by the number of people per square kilometer of area	World Development Indicators (World Bank, 2020c)

Note: This table provides a data description of all variables considered in this study
Source: Created by authors

This study is limited to certain ICT variables (mobile broadband and internet) and FI (deposits, credits and mobile transactions) as the independent variable. According to International Telecommunication Union (2020), internet and mobile broadband are included in the ICT usage sub-index in calculating the ICT Development Index, which is the second stage, after the ICT access sub-index, in the evolution toward an information society.

3.2 Methodology

In this study, we aim to measure the impact of ICT, FI and the interaction between ICT and FI on economic growth using a panel data model. The panel data were analyzed using an econometric approach, specifically the generalized method of moments (GMM), developed by Hansen (1982). In economics, most explanatory variables are not perfectly exogenous, leading to the issue of endogeneity. These variables can be predetermined (correlated with past observation-specific disturbances) or endogenous (correlated with past and current observation-specific disturbances). The independent variables used in this research, such as GDP per capita growth, ICT (mobile broadband and internet) and FI, are often considered endogenous in econometric models. When independent variables are endogenous, standard estimation techniques like ordinary least squares can produce biased and inconsistent estimates, undermining the validity of the conclusions drawn from the analysis. As a result, several methods, including GMM, have been developed to mitigate this problem.

GMM became a popular method and was further developed by Arellano and Bond (1991), who introduced difference GMM, where the lagged dependent variable is included as an independent variable. However, the disadvantage of using difference GMM was eventually discovered after the paper publication by Caselli *et al.* (1996) and Blundell and Bond (1998) revisited the work and developed newer and more efficient ways to estimate GMM, known as system GMM. System GMM performs better than Arellano and Bond's estimator when the autoregressive coefficient is relatively high, and the number of periods is small. The system GMM estimation requires that the series ($y_{i,1}$, $y_{i,\ 2}$,…$y_{i,\ T}$) are mean stationary, meaning they have a constant mean, $\frac{\eta_i}{1-\alpha}$ for each country i. Unlike difference GMM, which only uses the equation in first differences, system GMM combines equations in levels and first differences.

As noted by Roodman (2009), the use of system GMM estimators must be done with great caution, and several checks must be performed before relying on the estimation results, especially when T is small and the number of internally determined instruments is high. There is a trade-off in the lag distance used to create instrument variables and the depth of the sample used. Because too many instruments can overfit instrumented variables – failing to remove their endogenous components and biasing the coefficient estimates (Roodman, 2009) – we keep the number of instruments to a minimum. For the lagged real GDP per capita, we use the first difference lagged one period for the equations in levels as instruments. For the equations in first difference, we use the first lagged value. For the other variables, which are assumed endogenous, we use the second lagged value as instruments. This study adopted the two-step system GMM with Windmeijer (2005) small sample robust correction. The lag of GDP per capita growth ($y_{i,t\ -\ 1} - y_{i,t\ -\ 2}$) is used as an instrument for the first difference lagged one period for the equation in level. Following Andrianaivo and Kpodar (2011) and Chatterjee (2020), this study uses a two-step system GMM small sample robust correction based on Windmeijer (2005).

Following Barro (1991) and Waverman *et al.* (2005), we examine the relationship between ICT and economic growth using a standard endogenous growth model. The equation is as follows:

$$Y_{i,t} = \alpha_0 + \alpha_1 X_{i,t} + \eta_i + \varepsilon_{i,t}$$

where the dependent variable ($Y_{i,\ t}$) is explained by a set of exogenous variables ($X_{i,\ t}$) and unobservable individual-specific factors ε(i,t) is the error term, and (*i*) and (*t*) represent the country and time period, respectively. To examine whether ICT impacts economic growth, this study follows the specification model used by Andrianaivo and Kpodar (2011), Chatterjee (2020) and Myovella *et al.* (2019):

$$log\, y_{i,t} - y_{i,t-1} = \alpha_0 + \alpha_1\, log\, y_{i,t-1} - y_{i,t-2} + \alpha_2 ICT_{i,t} + \alpha_3 X_{i,t} + \eta_i + \varepsilon_{i,t} \quad (1)$$

where $y_{i,\ t} - y_{i,t-1}$ is GDP per capita growth, $y_{i,t-1} - y_{i,t-2}$ is lag GDP per capita growth, $ICT_{i,t}$ is ICT variables (mobile broadband and internet), $X_{i,t}$ is a set of economic growth determinants (education, workforce, trade openness, value-added of industry, value-added of services and foreign direct investment), η_i is an unobserved country-specific effect, ε(i,t) is an error term, i is countries, and *t* is time.

Second, we examine whether FI impacts economic growth using a dynamic panel model:

$$log y_{i,t} - y_{i,t-1} = \beta_0 + \beta_1\, log y_{i,t-1} - y_{i,t-2} + \beta_2 FI_{i,t} + \beta_3 X_{i,t} + \eta_i + \varepsilon_{i,t} \quad (2)$$

where $y_{i,t} - y_{i,t-1}$ is GDP per capita growth, $y_{i,t-1} - y_{i,t-2}$ is lag GDP per capita growth, $FI_{i,t}$ is FI variables that consist of deposits, credits and mobile transactions, $X_{i,t}$ is a set of economic growth determinants (education, workforce, trade openness, value-added of industry, value-added of services, foreign direct investment), η_i is an unobserved country-specific effect, ε(i,t) is an error term, i is countries, and *t* is time.

Third, to examine whether FI represents a channel through which ICT can encourage economic growth, this study regresses the interaction variable of ICT and FI as follows:

$$log\, y_{i,t} - y_{i,t-1} = \gamma_0 + \gamma_1\, log\, y_{i,t-1} - y_{i,t-2} + \gamma_2 ICT_{i,t} + \gamma_3 FI_{i,t} + \gamma_4 ICTx\, FI_{i,t} + \gamma_5 X_{i,t} + \eta_i + \varepsilon_{i,t} \quad (3)$$

where $y_{i,t} - y_{i,t-1}$ is GDP per capita growth, $y_{i,t-1} - y_{i,t-2}$ is lag GDP per capita growth, $ICT \times FI_{i,t}$ is an interaction variable of ICT and FI, $X_{i,t}$ is a set of economic growth determinants (education, workforce, trade openness, value-added of industry, value-added of services, foreign direct investment), η_i is an unobserved country-specific effect, ε(i,t) is an error term, i is countries, and *t* is time.

The models [equations (1)–(3)] are dynamic panel data model, a panel regression with lagged dependent variable ($y_{i,t\ -\ 1} - y_{i,t\ -\ 2}$) on the right-hand side. This study focuses on long-term economic growth, so we divide the study period into five subperiods (three-year averages): 2005–2007, 2008–2010, 2011–2013, 2014–2016 and 2017–2019. The focus on long-term economic growth aligns with the endogenous growth theory developed by Romer (1990), who investigated the dynamics of the economy and the factors that influence it. Andrianaivo and Kpodar (2011) also used several years average on dependent variable, because their study focuses on long-term economic growth, and to avoid stationary issues associated with annual data.

Fourth, this study considers the impact of ICT on FI based on Andrianaivo and Kpodar (2011) and Chatterjee (2020) using a test that applies pooled least square (PLS), random effects and fixed effects to static linear panel data according to the following equation:

$$FI_{i,t} = \delta_0 + \delta_1 ICT_{i,t} + \delta_2 log\, y_{i,t} + \delta_3 X_{i,t} + \varepsilon_{i,t} \quad (4)$$

where $FI_{i,t}$ is FI, and we measure by deposit accounts, outstanding credits, ATM numbers, banking branch numbers and mobile transaction numbers; $ICT_{i,t}$ variable represents a variable of interest that comprises mobile broadband as measured by mobile-broadband subscriptions per 100 people and internet as measured by the percentage of people using the internet; $(y_{i,t})$ is GDP per capita and $(X_{i,t})$ is a set of FI determinants (education and population density). In testing the impact of ICT on FI, the use of annual data in the research period is 2005–2019.

Fifth, we examine the impact of ICT to FI gaps – namely, gender, education and income gaps – which are measured by financial institution accounts (% of the population), loans from financial institutions (% of the population) and digital payment service use (% of the population). In this study, adding a new equation model with the dependent variable FI gap, which has never been examined in previous research, will explain the role of ICT in expanding financial access for each population group. This model will also ascertain the supposition of Sioson and Kim (2019) about the role of fintech in bridging the gender gap in FI.

The study tests the impact of ICT on FI gaps by applying PLS, random effects and fixed effects to static linear panel data according to the following equation:

$$FIGap_{i,t} = \zeta_0 + \zeta_1 ICT_{i,t} + \zeta_2 log\, y_{i,t} + \zeta_3 X_{i,t} + \varepsilon_{i,t} \quad (5)$$

where $FIGap_{i,t}$ is the FI gap, $ICT_{i,t}$ is a variable of interest that comprises mobile broadband as measured by mobile broadband subscriptions per 100 people and internet as measured by the percentage of people using the internet, $(y_{i,t})$ is GDP per capita and $(X_{i,t})$ is a set of FI determinants (education, and population density). In testing the influence of ICT on the FI gap using data from 2011, 2014 and 2017 according to the availability of gap data in FI from the Global Findex database, the World Bank.

We conduct stationarity tests by using augmented Dickey–Fuller unit root test as shown in Table 2. The results reveal that almost all variables are stationary, except mobile transaction variable and internet variable in low-income countries.

4. Empirical results

4.1 Statistical features of the data

The data of this study are taken from the World Bank, the ITU and the IMF. Before we examine our main hypothesis, a descriptive story of data set in order as shown in Table 3.

In general, indicators of economic growth, ICT, FI and control variables used in this research are the highest in the high-income country group. In the ICT indicator, namely, log mobile broadband, the highest is in the high-income country group, namely, Macau, United Arab Emirates and Japan. Then, the highest internet indicators are in the high-income countries, namely, Kuwait, Qatar and Iceland.

For FI indicators, there are three main variables, namely, log deposit log, log credit log and log mobile transaction. Regarding log deposit indicators, the highest are Nepal, Mexico and Guyana. The highest log credit indicators are Iraq, Kazakhstan and Uzbekistan. The highest mobile transaction logs are in Uganda, Tonga and Seychelles.

In the first step, we will examine the ICT and FI variable and the interaction variable of ICT and FI using PLS, random effects and fixed effects testing. This estimation reveals that lag GDP significantly and positively affects GDP. We compare the value of the GDP growth lag coefficient between the PLS model, which is significant, and the GDP growth lag coefficient of other models to determine that the model used is unbiased and optimal. A coefficient value of PLS higher than other models indicates that the PLS model tends to be upward-biased. Next, we compare the Sys GMM model with the fixed-effects model. The

Table 2. Panel data unit root test

Variables	Statistic	*p*-value
Average Data 3 years		
GDP per capita (growth)	708.767	0.000
Mobile broadband	4473.361	0.000
Internet	1163.220	0.000
Deposit	544.360	0.000
Loan	2225.178	0.000
Mobile transaction	0.000	1.000
Education	784.180	0.000
Value-added of industry	1003.795	0.000
Value-added of services	1359.432	0.000
Foreign direct investment	1830.467	0.000
Trade openness	739.353	0.000
Workforce	872.374	0.000
Annual data high-income countries		
Deposit	413.738	0.000
Loan	953.065	0.000
ATM	1283.552	0.000
Bank branches per 1.000 km^2	432.215	0.000
Bank branches per 100.000 adults	310.242	0.000
Mobile transaction	218.685	0.000
Internet	356.001	0.000
Mobile broadband	2394.166	0.000
GDP per capita (value)	411.738	0.000
Population density	1754.834	0.000
Annual data low-income countries		
Deposit	282.720	0.000
Loan	485.701	0.000
ATM	1275.759	0.000
Bank branches per 1.000 km^2	409.904	0.000
Bank branches per 100.000 adults	363.611	0.000
Mobile transaction	839.678	0.000
Internet	56.141	1.000
Mobile broadband	1013.292	0.000
GDP per capita (value)	273.694	0.000
Population density	1342.655	0.000

Note: This table provides the results on panel data unit root test by using augmented Dickey–Fuller (ADF) unit root test
Source: Created by authors

fixed-effects model has a lower coefficient than other models or is downward-biased, including the Sys GMM model. Therefore, that condition meets the criteria test, concluding that the Sys GMM model is unbiased and optimal.

In the second step, we examine mobile broadband and internet according to equation (4) based on a static linear panel data model to test whether ICT is a determinant of FI. However, employing PLS engendered a problem common to the ordinary least squares approach: omitted variable bias. This equation required introducing a control variable and using random-effects and fixed-effects models. Choosing between PLS and the random-effects model required using the Breusch and Pagan Lagrange multiplier test and determining

Table 3. Descriptive statistics

	Min	Max	Mean	SD
Log GDP				
High-income countries	0.438	9.144	5.610	1.210
Low-income countries	–2.526	5.835	3.385	1.137
Log mobile broadband				
High-income countries	–4.605	5.820	3.489	1.420
Low-income countries	–3.912	4.748	2.020	1.853
Internet				
High-income countries	0.93	99.71	53.797	26.106
Low-income countries	0.15	76.12	14.897	14.733
Log deposit				
High-income countries	2.523	6.893	6.229	0.929
Low-income countries	2.089	8.301	5.751	1.123
Log credit				
High-income countries	–0.844	6.862	3.452	1.456
Low-income countries	–1.966	11.487	3.525	2.367
Log mobile transaction				
High-income countries	–0.580	9.995	6.094	2.473
Low-income countries	–1.609	6.869	4.710	2.202
Education				
High-income countries	26.07	162.42	97.611	17.053
Low-income countries	10.43	99.61	55.572	23.684
Value-added of industry				
High-income countries	3.98	82.93	27.868	14.008
Low-income countries	1.39	64.39	24.300	10.463
Value-added of services				
High-income countries	16.58	96.11	59.177	11.895
Low-income countries	18.02	73.77	47.304	9.199
Foreign direct investment				
High-income countries	–16.77	386.07	7.484	21.060
Low-income countries	–11.2	79.02	4.204	6.472
Trade openness				
High-income countries	24.05	431.68	103.286	62.669
Low-income countries	0.25	286.29	74.601	33.879
Workforce				
High-income countries	30.84	87.31	55.741	9.576
Low-income countries	30.77	87.26	60.824	14.183

Notes: This table reports the test results of some commonly used descriptive statistics (minimum, maximum, mean and standard deviation in high- and low-income countries). These variables have been averaged for three years, aligning with the research focus on long-term economic growth
Source: Created by authors

whether a random-effects or fixed-effects model would be optimal and unbiased using the Hausman test. Upon testing for autocorrelation and heteroskedasticity and determining problems with the model in these dimensions, the study adopted a generalized least squares (GLS) estimator with a fixed-effect model [2].

4.2 Predictability test results

4.2.1 The impact of ICT and financial inclusion on economic growth. First, we test whether ICT and FI separately improve economic growth using equations (1) and (2) as shown in Table 4.

It is generally apparent that ICT has a significant and positive impact on economic growth, with the coefficient value of mobile broadband being higher than the internet. This finding supports the endogenous economic growth theory concerning the effect of technology on economic growth. This result aligns with the findings of Chatterjee (2020), Choi and Hoon Yi (2009), Pohjola (2000) and Vu (2011). In contrast, all FI variables demonstrate an insignificant impact on economic growth. The results in Table 4 are consistent with the hypothesis that ICT has a significant and positive impact on economic growth but inconsistent with the hypothesis that FI has a significant and positive impact on economic growth.

Table 5 compares the effects of ICT and financial inclusion on economic growth between high- and low-income countries. These estimation results show that the internet variable significantly and positively impacts economic growth in high- and low-income countries. Meanwhile, mobile broadband significantly and positively impacts economic growth in high-income countries but has an insignificant impact on economic growth in low-income countries. So, the results in Table 5 are consistent with the hypothesis that ICT has a significant and positive impact on economic growth.

The notion of critical mass may explain this result, which must reach a certain level for ICT variables to influence economic growth. However, low-income countries still need to achieve a critical mobile broadband mass. Similarly, according to Roller and Waverman (2001), countries must reach a critical mass of mobile phone penetration above 40 to improve economic growth.

The three-year average of active mobile broadband subscriptions per 100 inhabitants represents the study's ICT mobile broadband variable. For countries with a three-year average of 42.77 mobile-broadband subscriptions per 100 inhabitants, the ICT variable mobile broadband significantly impacts economic growth. Notably, the average for high-income countries is 55.77, but the average for low-income countries is only 20.18. These averages correspond to the different impacts on economic growth. Given these observations, the estimation of the critical mass of the ICT mobile-broadband variable is 20.18 < critical mass mobile-broadband < 42.77.

4.2.2 The impact of the interaction variable of ICT and financial inclusion on economic growth. Table 6 presents the effects of ICT and FI interaction variables on economic growth as measured using equation (3). The interaction variable of ICT and FI is positive and significantly impacts economic growth (Model 6.4). In Model 6.4, a partial derivative of $log\ y_{i,t} - y_{i,t-1}$ with respect to $FI_{i,t}$ is $\gamma_3 + \gamma_4\ ICT_{i,t}$ [equation (3)], which indicates a change of 0.197 (−0.013 + 0.210) in the slope of log economic growth on log deposits given a 1% change in the internet variable.

The results in Table 6 are consistent with the hypothesis that the interaction variable of ICT and FI has a significant and positive impact on economic growth, but only in specific model. These results indicate that internet facilitates access to financial services. Subsequently, it encourages bank intermediation in terms of funding and provides credit for businesses, with the additional capital from the bank hopefully increasing economic activity. Unfortunately, the new variable of FI (mobile transactions) is not significant to economic growth while interacting with mobile broadband.

Then, Table 7 compares the impact of the ICT and FI interaction variable on economic growth between high- and low-income countries. The interaction between the internet and

Table 4. The impact of ICT and financial inclusion on economic growth

	Dependent variable: growth of GDP per capita (log)				
Independent variables	Model 4.1	Model 4.2	Model 4.3	Model 4.4	Model 4.5
Lag of GDP growth (log)	0.167 (0.273)	0.177 (0.185)	0.147 (0.294)	0.043 (0.763)	0.485** (0.038)
Mobile broadband	0.125** (0.016)				
Internet		0.022*** (0.000)			
Deposits			0.120 (0.473)		
Credits				0.066 (0.206)	
Mobile transactions					−0.060 (0.355)
Education	0.020*** (0.000)	0.010** (0.012)	0.020** (0.011)	0.027*** (0.000)	0.012 (0.127)
Value-added of industry	0.026** (0.019)	0.018* (0.057)	0.033* (0.061)	0.019 (0.147)	0.035*** (0.005)
Value-added of services	0.039** (0.012)	0.019 (0.184)	0.038* (0.083)	0.045*** (0.007)	0.039* (0.097)
Foreign direct investment	0.004 (0.432)	0.012** (0.024)	0.009 (0.281)	0.004 (0.630)	0.012 (0.168)
Trade openness	0.001 (0.391)	0.000 (0.942)	−0.006 (0.296)	0.002 (0.317)	0.006 (0.340)
Workforce	0.012* (0.060)	0.009 (0.115)	0.013 (0.138)	0.010 (0.173)	−0.017 (0.410)
Constant	–1.677 (0.063)	−0.001 (0.999)	−1.948 (0.162)	−1.645 (0.100)	−0.689 (0.760)
Observations	316	339	107	294	27
Arellano–Bond test	*p-val.* (AR) 1: 0.038	*p-val.* (AR) 1:0.022	*p-val.* (AR) 1:0.186	*p-val.* (AR) 1:0.083	*p-val.* (AR) 1:0.413
	p-val. (AR) 2: 0.709	*p-val.* (AR) 2:0.297	*p-val.* (AR) 2:0.445	*p-val.* (AR) 2:0.762	*p-val.* (AR) 2: -
Hansen J statistics	Prob. Chi^2: 0.023	Prob. Chi^2: 0.010	Prob. Chi^2: 0.430	Prob. Chi^2: 0.080	Prob. Chi^2: 0.644

Notes: This table reports test results on the impact of ICT and financial inclusion for economic growth with the five Sys GMM models (Model 4.1–4.5). The Arellano–Bond test results for almost all of the above models show a *p*-value AR (2) > 0.05, which means there is no autocorrelation. In addition, the Hansen J statistics test result shows the chi-square probability value > 0.01. So, the conclusion is that the instrument used in this study is valid. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

Source: Created by authors

Table 5. The impact of ICT and financial inclusion on economic growth in high- and low-income countries

	Dependent variable: growth of GDP per capita (log)								
	High-income countries						Low-income countries		
Independent variables	Model 5.1	Model 5.2	Model 5.3	Model 5.4	Model 5.5	Model 5.6	Model 5.7	Model 5.8	Model 5.9
Lag of GDP growth (log)	0.053 (0.646)	0.018 (0.876)	−0.257 (0.859)	−0.073 (0.540)	0.400 (0.376)	0.246 (0.139)	0.331* (0.064)	0.083 (0.665)	0.271 (0.117)
Mobile broadband	0.313*** (0.002)					−0.007 (0.894)			
Internet		0.018*** (0.001)					0.014** (0.046)		
Deposits			−0.185 (0.505)					0.537** (0.014)	
Credits				−0.003 (0.964)					0.037 (0.443)
Mobile transactions					0.030 (0.667)				
Education	0.009 (0.167)	0.007 (0.388)	0.021 (0.473)	0.021* (0.073)	−0.000 (0.998)	0.019*** (0.004)	0.010* (0.059)	0.005 (0.454)	0.017*** (0.007)
Value-added of industry	−0.002 (0.941)	0.002 (0.915)	0.019 (0.553)	−0.006 (0.820)	0.028 (0.476)	0.035** (0.020)	0.015 (0.300)	0.030* (0.064)	0.017 (0.250)
Value-added of services	0.019 (0.406)	0.020 (0.352)	0.079* (0.048)	0.041* (0.099)	0.038 (0.451)	0.014 (0.292)	0.000 (0.973)	−0.000 (0.984)	0.005 (0.711)
Foreign direct investment	0.003 (0.740)	0.004 (0.671)	−0.132 (0.507)	−0.002 (0.857)	0.006 (0.799)	0.009 (0.168)	0.014** (0.049)	0.011 (0.113)	−0.001 (0.958)
Trade openness	0.002 (0.371)	0.001 (0.578)	−0.001 (0.902)	0.003 (0.355)	0.007 (0.107)	−0.006* (0.085)	−0.003 (0.320)	−0.005 (0.302)	−0.003 (0.565)
Workforce	0.024 (0.135)	0.019 (0.170)	0.058 (0.181)	0.024 (0.207)	−0.029 (0.186)	0.007 (0.311)	0.005 (0.378)	0.003 (0.683)	0.004 (0.609)
Constant	0.591 (0.685)	1.267 (0.294)	−1.943 (0.791)	0.037 (0.982)	1.333 (0.603)	0.054 (0.961)	0.992 (0.263)	−0.736 (0.548)	0.704 (0.512)
Observations	184	188	24	153	24	132	151	98	150
Arellano–Bond test	*p-val*. (AR) 1:0.288 *p-val*. (AR) 2:0.660	*p-val.* (AR) 1:0.224 *p-val.* (AR) 2:0.175	*p-val.* (AR) 1:0.960 *p-val.* (AR) 2: -	*p-val*. (AR) 1:0.690 *p-val*. (AR) 2:0.461	*p-val.* (AR) 1:0.666 *p-val.* (AR) 2:0.305	*p-val.* (AR) 1:0.038 *p-val.* (AR) 2:0.866	*p-val*. (AR) 1:0.046 *p-val*. (AR) 2:0.573	*p-val.* (AR) 1:0.358 *p-val.* (AR) 2:0.085	*p-val*. (AR) 1:0.036 *p-val*. (AR) 2:0.952
Hansen J statistics	Prob. Chi^2: 0.152	Prob. Chi^2: 0.135	Prob. Chi^2: 0.857	Prob. Chi^2: 0.080	Prob. Chi^2: 0.561	Prob. Chi^2: 0.126	Prob. Chi^2: 0.035	Prob. Chi^2: 0.252	Prob. Chi^2: 0.205

Notes: This table reports test results on the impact of ICT and financial inclusion for economic growth in high- and low-income countries with the nine Sys GMM models (Model 5.1–5.9). The Arellano–Bond test results for almost all of the above models show a p-value AR (2) > 0.05, which means there is no autocorrelation. In addition, the Hansen J statistics test result shows the chi-square probability value > 0.01. So, the conclusion is that the instrument used in this study is valid. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

Source: Created by authors

Table 6. The impact of the interaction variable of ICT and financial inclusion on economic growth

	Dependent variable: growth of GDP per capita (log)				
Independent variables	Model 6.1	Model 6.2	Model 6.3	Model 6.4	Model 6.5
Lag of GDP growth (log)	0.065 (0.705)	0.131 (0.427)	0.406 (0.308)	0.202 (0.251)	0.121 (0.389)
Mobile Broadband	0.144 (0.820)	0.242** (0.047)	0.346 (0.402)		
Internet				0.104** (0.016)	0.027*** (0.000)
Deposits	0.013 (0.961)			0.210 (0.252)	
Credits		0.135 (0.193)			0.038 (0.564)
Mobile Transactions			0.097 (0.731)		
Mobile broadband × Deposits	−0.026 (0.811)				
Mobile broadband × Credits		−0.037 (0.209)			
Mobile broadband × mobile transaction			−0.042 (0.621)		
Internet × Deposits				−0.013** (0.039)	
Internet × Credits					−0.001 (0.351)
Education	0.026** (0.012)	0.021*** (0.000)	0.011 (0.236)	0.011 (0.122)	0.011** (0.016)
Value-added of industry	0.039 (0.110)	0.029** (0.021)	0.028* (0.087)	0.024 (0.117)	0.018* (0.065)
Value-added of services	0.051* (0.063)	0.050*** (0.001)	0.027 (0.351)	0.026 (0.145)	0.028* (0.057)
Foreign direct investment	0.006 (0.525)	0.004 (0.617)	0.008 (0.672)	0.013 (0.139)	0.012* (0.093)
Trade openness	−0.003 (0.528)	0.001 (0.484)	0.009 (0.112)	−0.005 (0.318)	−0.000 (0.848)
Workforce	0.013 (0.318)	0.012* (0.085)	−0.012 (0.439)	0.012 (0.117)	0.009 (0.140)
Constant	−2.206 (0.342)	−2.702*** (0.008)	−1.058 (0.602)	−1.843 (0.191)	−0.461 (0.617)
Observations	95	269	26	106	291
Arellano–Bond test	*p-val.* (AR) 1:0.230	*p-val.* (AR) 1:0.114	*p-val.* (AR) 1:0.313	*p* value (AR) 1:0.118	*p* value (AR) 1:0.050
	p-val. (AR) 2:0.372	*p-val.* (AR) 2:0.714	*p-val.* (AR) 2: -	*p* value (AR) 2:0.107	*p* value (AR) 2:0.353
Hansen J statistics	Prob. Chi^2: 0.307	Prob. Chi^2: 0.114	Prob. Chi^2: 0.547	Prob. Chi^2: 0.098	Prob. Chi^2: 0.068

Notes: This table reports test results on the impact of interaction variables of ICT and financial inclusion for economic growth in high- and low-income countries with the five Sys GMM models (Model 6.1–6.5). The Arellano–Bond test results for almost all of the above models show a *p*-value AR (2) > 0.05, which means there is no autocorrelation. In addition, the Hansen J statistics test result shows the chi-square probability value > 0.01. So, the conclusion is that the instrument used in this study is valid. Finally, *, ** and *** denote statistical significance at the 10, 5 and 1% levels, respectively

Source: Created by authors

Table 7. The impact of the interaction variable of ICT and financial inclusion on economic growth in high- and low-income countries

	Dependent variable: Growth of GDP per capita (log)							
	High-income countries				Low-income countries			
Independent variables	Model 7.1	Model 7.2	Model 7.3	Model 7.4	Model 7.5	Model 7.6	Model 7.7	Model 7.8
Lag of GDP growth (log)	−0.260 (0.927)	−0.024 (0.857)	−0.529 (0.224)	−0.045 (0.717)	−0.008 (0.970)	0.224 (0.128)	0.221 (0.275)	0.288 (0.131)
Mobile broadband	0.494 (0.926)	0.668*** (0.007)			0.246 (0.755)	−0.007 (0.957)		
Internet			0.248 (0.277)	0.040*** (0.000)			0.046 (0.307)	0.003 (0.856)
Deposits	−0.268 (0.752)		0.684 (0.457)		0.264 (0.666)		0.344 (0.139)	
Credits		0.352 (0.208)		0.293* (0.057)		0.061 (0.441)		−0.029 (0.722)
Mobile broadband × Deposits	−0.032 (0.968)				−0.051 (0.692)			
Mobile broadband × Credits		−0.111 (0.155)				−0.002 (0.935)		
Internet × Deposits			−0.032 (0.345)				−0.005 (0.471)	
Internet × Credits				−0.006** (0.020)				0.003 (0.429)
Education	0.010 (0.961)	0.012 (0.162)	−0.006 (0.769)	0.008 (0.372)	0.030 (0.334)	0.019*** (0.002)	0.005 (0.552)	0.011** (0.035)
Value-added of industry	0.013 (0.790)	0.001 (0.963)	−0.023 (0.522)	0.003 (0.907)	0.033 (0.149)	0.033** (0.021)	0.022 (0.182)	0.017 (0.268)
Value-added of services	0.074 (0.489)	0.033 (0.166)	−0.006 (0.907)	0.034 (0.116)	0.024 (0.361)	0.017 (0.190)	0.005 (0.788)	0.002 (0.835)
Foreign direct investment	−0.023 (0.915)	0.005 (0.599)	0.006 (0.959)	0.007 (0.476)	0.006 (0.661)	−0.005 (0.739)	0.012 (0.119)	0.013 (0.547)
Trade openness	−0.001 (0.947)	0.001 (0.507)	0.000 (0.974)	0.000 (0.872)	−0.005 (0.530)	−0.004 (0.228)	−0.004 (0.504)	−0.003 (0.385)
Workforce	0.093** (0.046)	0.034* (0.077)	0.061** (0.025)	0.028 (0.103)	0.002 (0.915)	0.005 (0.556)	0.004 (0.534)	0.004 (0.535)
Constant	−3.234 (0.760)	−1.779 (0.305)	−0.165 (0.979)	−0.842 (0.580)	−1.372 (0.695)	−0.140 (0.900)	−0.609 (0.593)	1.130 (0.268)
Observations	24	150	24	153	84	128	95	147
Arellano–Bond test	*p-val.* (AR) 1:0.999	p-val. (AR) 1:0.732	p-val. (AR) 1:0.957	p-val. (AR) 1:0.460	p-val. (AR) 1:0.285	p-val. (AR) 1:0.037	p-val. (AR) 1:0.177	p-val. (AR) 1:0.046
	p-val. (AR) 2: -	p-val. (AR) 2:0.763	p-val. (AR) 2: -	p-val. (AR) 2:0.217	p-val. (AR) 2:0.155	p-val. (AR) 2:0.783	p-val. (AR) 2:0.031	p-val. (AR) 2:0.542
Hansen J statistics	Prob. Chi^2: 0.523	Prob. Chi^2: 0.344	Prob. Chi^2: 0.985	Prob. Chi^2: 0.308	Prob. Chi^2: 0.160	Prob. Chi^2: 0.145	Prob. Chi^2: 0.148	Prob. Chi^2: 0.041

Notes: This table reports test results on the impact of interaction variables of ICT and financial inclusion for economic growth in high- and low-income countries with the eight Sys GMM models (Model 7.1–7.8). The Arellano–Bond test results for almost all of the above models show a *p*-value AR (2) > 0.05, which means there is no autocorrelation. In addition, the Hansen J statistics test result shows the chi-square probability value > 0.01. So, the conclusion is that the instrument used in this study is valid. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

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deposits significantly and positively impacts economic growth in high-income countries. The interaction between the internet and credits in high-income countries significantly and positively impacts economic growth (Model 7.4) when we include the model's primary terms (internet and credits). In Model 7.4, the partial derivative of $log\ y_{i,t} - y_{i,t-1}$ with respect to $FI_{i,t}$ is $\gamma_3 + \gamma_4\ ICT_{i,t}$ [equation (3)], producing a change of 0.287 (−0.006 + 0.293) in the slope of log economic growth on credits given a 1% change in the internet variable. These results in Table 7 are consistent with the hypothesis that the interaction variable of ICT and FI has a significant and positive impact on economic growth, but only in specific model.

4.2.3 The impact of variable of ICT on financial inclusion. Table 8 compares the estimation output between high- and low-income countries to examine whether the ICT variable determines FI.

The variable of ICTs has an impact on FI as shown in Table 8. In general, both ICT variables (mobile broadband and internet) in overall countries significantly and positively impact FI. The results support the hypothesis that ICT positively impacts FI, demonstrating that ICT is a determinant of FI, aligning with the findings of Andrianaivo and Kpodar (2011) and Chatterjee (2020).

It is interesting to note that the differing results demonstrate the impact of ICT on banking branches. Although the internet and mobile broadband has a significant and positive impact on banking branches in low-income countries, it has a significant and negative impact on high-income countries. This finding suggests that although internet and mobile broadband usage has increased in low-income countries, residents of those countries continue to require access to physical banking services at bank branches. In contrast, increased internet and mobile broadband usage in high-income countries has made bank branches obsolete.

4.2.4 The impact of ICT variables on financial inclusion gaps. ICT variables have a diverse impact on FI gaps in overall countries. While the effect of ICT variables on certain FI variables is significant and negative, the effect is significant and positive or not significant for other variables. Nonetheless, certain variables having a significant and negative impact suggest that increasing ICT successfully reduces FI gaps. Then, Tables 9, 10 and 11 below compares the calculation output to compare the effects of the ICT variable on FI gaps in high- and low-income countries.

The impact of ICT variables on FI gaps is diverse across both country groups (Tables 9, 10 and 11). The impact of ICT variables on specific FI gaps is significant and negative, significant and positive or not significant for other gaps. The negative impact on certain variables suggests that ICT can reduce FI gaps; probing these results demonstrates that ICT variables significantly reduce FI gaps in high-income countries alone. Thus, high-income countries successfully reduce financial gaps, suggesting that a high-income level is a prerequisite for effectively reducing FI gaps. These results align with the hypothesis that ICT has a significant and negative impact on FI, although only in some models in high-income countries.

4.2.5 Robustness check. We consider the sensitivity of the coefficient of the ICT and FI interaction variable to the sample's composition using the specifications in Model 4.1 and 4.2 of Table 4 and Model 6.4 of Table 6 to test the result's robustness. We begin the test by selecting observations randomly, with 98% of the observations without replacement. Next, we repeat the baseline regression 250 times, producing coefficient values that form a normal distribution (Figure 1). The average coefficient for the variable of interest in models is very close to the coefficient of the total sample.

The other regression tests run between 85 and 98% of the observations using the same procedures, leading to the coefficient of the variable of interest shifting away from the coefficient of the total sample. This movement indicates that by replicating the estimate for

Table 8. The impact of ICT on financial inclusion in high- and low-income countries

			Dependent variable: Financial inclusion High-income countries				
Independent variables	Model 8.1 (Deposits) FE-GLS	Model 8.2 (Deposits) FE-GLS	Model 8.3 (Credits) FE-GLS	Model 8.4 (Credits) FE-GLS	Model 8.5 (Mobile transactions) FE-GLS	Model 8.6 (Mobile transactions) FE-GLS	Model 8.7 (ATM) FE-GLS
Mobile broadband	0.027*** (0.000)		0.074*** (0.000)		0.386*** (0.000)		2.204*** (0.000)
Internet		0.006*** (0.000)		0.012*** (0.000)		0.014 (0.301)	
GDP	0.260*** (0.000)	0.239*** (0.000)	0.457*** (0.000)	0.223*** (0.000)	−0.399 (0.387)	−0.949 (0.142)	21.889*** (0.000)
Education	0.004*** (0.000)	0.003*** (0.000)	0.001* (0.055)	−0.001 (0.156)	0.074*** (0.000)	0.086*** (0.000)	−0.0179 (0.423)
Population density	0.153*** (0.000)	0.175*** (0.000)	0.223*** (0.000)	0.232*** (0.000)	1.187*** (0.000)	1.203*** (0.000)	1.060 (0.164)
Constant	3.838 (0.000)	3.672 (0.000)	−1.629 (0.000)	0.235 (0.499)	−4.574 (0.244)	−0.754 (0.893)	−147.163 (0.000)
Observations	481	667	761	1.134	71	75	754
Independent variables			Dependent variable: Financial inclusion Low-income countries				
	Model 8.13 (Deposits) FE-GLS	Model 8.14 (Deposits) FE-GLS	Model 8.15 (Credits) FE-GLS	Model 8.16 (Credits) FE-GLS	Model 8.17 (Mobile transactions) FE-GLS	Model 8.18 (Mobile transactions) FE-GLS	Model 8.19 (ATM) FE-GLS
Mobile broadband	0.033*** (0.000)		0.083*** (0.000)		0.799*** (0.000)		0.310*** (0.000)
Internet		0.005*** (0.000)		0.017*** (0.000)		0.139*** (0.000)	
GDP	0.727*** (0.000)	0.766*** (0.000)	0.311*** (0.000)	0.555*** (0.000)	−0.605 (0.141)	−2.151*** (0.000)	6.835*** (0.000)
Education	0.014*** (0.000)	0.023*** (0.000)	−0.018*** (0.000)	−0.013*** (0.000)	0.007 (0.551)	−0.006 (0.717)	0.189*** (0.000)
Population density	0.260*** (0.000)	0.323*** (0.000)	−0.085** (0.012)	−0.183*** (0.000)	0.251** (0.020)	0.389* (0.071)	0.318 (0.140)
Constant	−1.303 (0.000)	−2.544 (0.000)	2.509 (0.000)	0.405 (0.485)	8.171 (0.001)	17.862 (0.000)	−50.007 (0.000)
Observations	242	379	328	579	129	140	330

Notes: This table reports test results on the impact of ICT on financial inclusion in high- and low-income countries with the 24 static linear panel data models (Model 8.1–8.24). We chose one of the several static linear panel data models between pooled least square (PLS), random-effects (RE) model or fixed-effects (FE) model, with several tests. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

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(*continued*)

Table 8. Continued

	Dependent variable: Financial inclusion High-income countries				
Independent variables	Model 8.8 (ATM) FE-GLS	Model 8.9 (Banking branch per 1.000 km2) RE	Model 8.10 (Banking branch per 1.000 km2) RE	Model 8.11 (Banking branch per 100.000 adults) RE	Model 8.12 (Banking branch per 100.000 adults) RE
Mobile broadband		−4.673 (0.110)		−1.353*** (0.000)	
Internet	0.393*** (0.000)		−0.456** (0.029)		−0.130*** (0.000)
GDP	22.221*** (0.000)	118.178*** (0.001)	162.778*** (0.000)	4.074* (0.055)	14.070*** (0.000)
Education	−0.081*** (0.000)	0.484 (0.301)	−0.144 (0.688)	−0.112*** (0.001)	−0.096*** (0.001)
Population density	2.015*** (0.000)	228.693*** (0.000)	170.487*** (0.000)	3.031* (0.060)	2.832* (0.062)
Constant	−166.262 (0.000)	−2080.381 (0.000)	−2145.72 (0.000)	−9.948 (0.631)	−104.296 (0. 000)
Observations	1,119	757	1,129	757	1,129
Independent variables	Dependent variable: Financial inclusion Low-income countries				
	Model 8.20 (ATM) FE-GLS	Model 8.21 (Banking branch per 1.000 km2) RE	Model 8.22 (Banking branch per 1.000 km2) FE-GLS	Model 8.23 (Banking branch per 100.000 adults) FE-GLS	Model 8.24 (Banking branch per 100.000 adults) FE-GLS
Mobile broadband		0.290*** (0.008)		−0.039 (0.115)	
Internet	0.222*** (0.000)		0.046*** (0.000)		0.096*** (0.000)
GDP	4.520*** (0.000)	2.365 (0.119)	1.647*** (0.000)	3.700*** (0.000)	2.558*** (0.000)
Education	0.116*** (0.000)	0.0503 (0.123)	0.039*** (0.000)	0.131*** (0.000)	0.080*** (0.000)
Population density	0.003 (0.984)	6.237*** (0.000)	3.853*** (0.000)	0.774*** (0.000)	0.389*** (0.009)
Constant	−32.674 (0.000)	−38.163 (0.001)	−24.864 (0.000)	−28.027 (0.000)	−17.981 (0.000)
Observations	535	340	581	334	581

Table 9. The impact of ICT on financial inclusion gap (financial institution accounts) in high- and low-income countries

	Dependent variable: Financial inclusion gap											
	High-income countries						Low-income countries					
Independent variables	Model 9.1 (Gender gap) RE	Model 9.2 (Gender gap) RE	Model 9.3 (Education gap) FE robust	Model 9.4 (Education gap) RE	Model 9.5 (Economic status gap) FE robust	Model 9.6 (Economic status gap) FE robust	Model 9.7 (Gender gap) RE	Model 9.8 (Gender gap) FE robust	Model 9.9 (Education gap) RE	Model 9.10 (Education gap) RE	Model 9.11 (Economic status gap) RE	Model 9.12 (Economic status gap) RE
Mobile broadband	0.201 (0.685)		−2.012** (0.031)		−2.140*** (0.005)		0.452 (0.143)		0.088 (0.811)		0.434 (0.274)	
Internet		−0.070** (0.048)		−0.001 (0.981)		−0.136** (0.015)		−0.083 (0.196)		0.006 (0.925)		0.014 (0.815)
GDP	−0.870 (0.403)	0.228 (0.846)	11.128 (0.201)	−5.043*** (0.009)	16.668*** (0.007)	14.552* (0.056)	1.248 (0.458)	−9.199 (0.279)	−1.214 (0.493)	−0.415 (0.833)	4.706*** (0.001)	5.044*** (0.001)
Education	−0.059 (0.162)	−0.036 (0.392)	−0.117* (0.069)	−0.137** (0.047)	−0.064 (0.122)	−0.096** (0.019)	−0.088* (0.098)	−0.011 (0.935)	0.006 (0.917)	−0.032 (0.590)	−0.041 (0.345)	−0.033 (0.475)
Population density	0.388 (0.517)	0.478 (0.427)	8.021 (0.585)	−1.184 (0.226)	10.270 (0.426)	14.869 (0.366)	1.168 (0.140)	36.858*** (0.000)	0.654 (0.420)	1.353 (0.122)	0.706 (0.210)	1.022* (0.083)
Constant	16.111 (0.066)	8.214 (0.398)	−106.315 (0.301)	85.103 (0.000)	−180.654 (0.021)	−176.762 (0.111)	−3.109 (0.778)	−82.553 (0.198)	24.172 (0.037)	17.238 (0.187)	−22.281 (0.015)	−26.030 (0.010)
Observations	194	197	194	197	193	196	92	107	92	107	90	104

Notes: This table reports test results on the impact of ICT on the financial inclusion gap (financial institution accounts) in high- and low-income countries with the 12 static linear panel data models (Model 9.1–9.12). We chose one of the several static linear panel data models between pooled least square (PLS), random-effects (RE) model or fixed-effects (FE) model, with several tests. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

Source: Created by authors

Table 10. The impact of ICT on financial inclusion gap (borrowed from a financial institution) in high- and low-income countries

	Dependent variable: Financial inclusion gap											
	High-income countries						Low-income countries					
Independent variables	Model 10.1 (Gender gap) RE	Model 10.2 (Gender gap) RE	Model 10.3 (Education gap) RE	Model 10.4 (Education gap) RE	Model 10.5 (Economic status gap) FE GLS	Model 10.6 (Economic status gap) FE GLS	Model 10.7 (Gender gap) RE	Model 10.8 (Gender gap) RE	Model 10.9 (Education gap) RE	Model 10.10 (Education gap) RE	Model 10.11 (Economic status gap) RE	Model 10.12 (Economic status gap) RE
Mobile broadband	−0.116 (0.744)		1.237** (0.029)		1.400*** (0.000)		0.018 (0.889)		0.031 (0.848)		0.346* (0.057)	
Internet		−0.002 (0.940)		0.084** (0.024)		0.043*** (0.000)		0.004 (0.861)		0.043 (0.102)		0.069** (0.019)
GDP	0.892* (0.057)	0.931 (0.103)	1.801** (0.017)	0.781 (0.398)	−0.424*** (0.001)	−0.696*** (0.000)	0.827 (0.110)	0.536 (0.308)	−0.770 (0.389)	−1.211 (0.162)	0.888 (0.317)	−0.074 (0.928)
Education	−0.003 (0.891)	−0.006 (0.773)	−0.042 (0.257)	−0.031 (0.394)	−0.066*** (0.000)	−0.055*** (0.000)	−0.030* (0.059)	−0.017 (0.285)	0.022 (0.447)	0.001 (0.971)	−0.019 (0.488)	−0.021 (0.377)
Population density	0.589** (0.019)	0.583** (0.019)	−1.061*** (0.009)	−1.033** (0.010)	−0.228*** (0.000)	−0.269*** (0.000)	0.119 (0.588)	0.066 (0.766)	−0.621 (0.141)	−0.485 (0.220)	−0.285 (0.435)	−0. 207 (0.516)
Constant	−7.466 (0.040)	−7.801 (0.071)	−5.509 (0.349)	2.251 (0.747)	9.811 (0.000)	14.110*** (0.000)	−3.671 (0.273)	−2.154 (0.535)	9.493 (0.106)	12.330 (0.033)	−2.682 (0.633)	3.270 (0.538)
Observations	197	200	197	200	184	189	92	107	92	107	90	104

Notes: This table reports test results on the impact of ICT on the financial inclusion gap (borrowed from a financial institution) in high- and low-income countries with the 12 static linear panel data models (Model 10.1–10.12). We chose one of the several static linear panel data models between pooled least square (PLS), random-effects (RE) model or fixed-effects (FE) model, with several tests. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

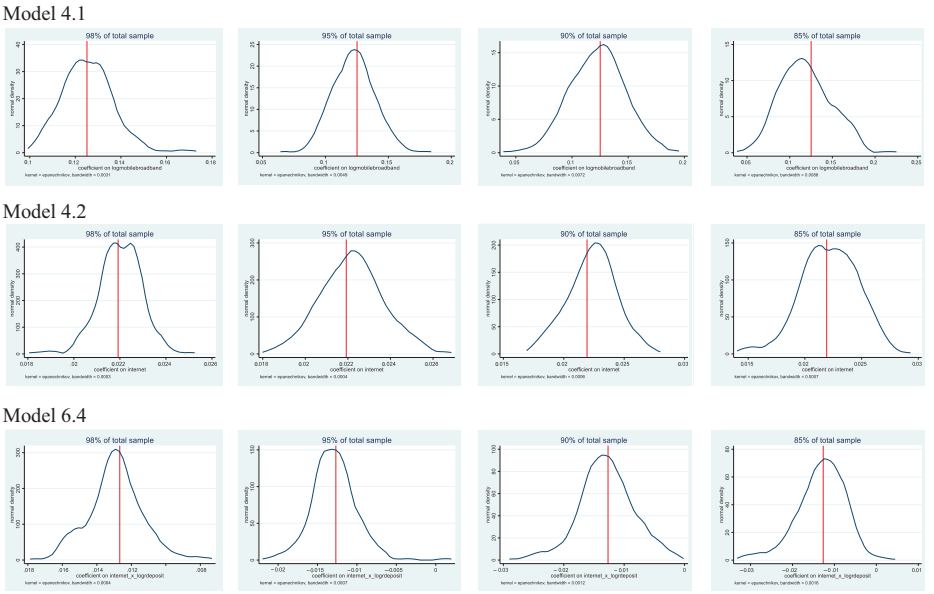
Source: Created by authors

Table 11. The impact of ICT on financial inclusion gap (made or received digital payments) in high- and low-income countries

	Dependent variable: Financial inclusion gap											
	High-income countries						Low-income countries					
Independent variables	Model 11.1 (Gender gap) RE	Model 11.2 (Gender gap) RE	Model 11.3 (Education gap) FE GLS	Model 11.4 (Education gap) FE GLS	Model 11.5 (Economic status gap) RE	Model 11.6 (Economic status gap) RE	Model 11.7 (Gender gap) PLS	Model 11.8 (Gender gap) PLS	Model 11.9 (Education gap) PLS	Model 11.10 (Education gap) PLS	Model 11.11 (Economic status gap) PLS	Model 11.12 (Economic status gap) PLS
Mobile broadband	−1.067 (0.404)		1.468*** (0.000)		−0.423 (0.745)		0.841 (0.213)		1.023 (0.245)		1.375* (0.060)	
Internet		−0.096* (0.069)		0.022*** (0.000)		−0.126** (0.017)		−0.074 (0.342)		0.201** (0.045)		0.133 (0.117)
GDP	−1.588 (0.181)	−0.476 (0.730)	−3.873*** (0.000)	−3.885*** (0.000)	−4.869*** (0.000)	−3.149*** (0.007)	2.147 (0.147)	3.341** (0.054)	−0.977 (0.610)	−2.909 (0.183)	4.753*** (0.004)	3.755** (0.045)
Education	−0.028 (0.622)	−0.029 (0.611)	−0.174*** (0.000)	−0.164*** (0.000)	−0.054 (0.252)	−0.049 (0.273)	−0.147** (0.002)	−0.104** (0.047)	−0.047 (0.427)	−0.096 (0.143)	−0.112** (0.025)	−0.130* (0.022)
Population density	0.956 (0.122)	0.906 (0.145)	0.788*** (0.000)	0.821*** (0.000)	0.899* (0.070)	0.865* (0.069)	0.014*** (0.000)	0.014*** (0.001)	0.002 (0.737)	0.003 (0.512)	0.008*** (0.048)	0.009** (0.027)
Constant	23.841 (0.007)	15.622 (0.116)	69.395 (0.000)	72.921*** (0.000)	64.023 (0.000)	54.048 (0.000)	−3.637 (0.679)	−10.460 (0.329)	26.002 (0.026)	40.463 (0.004)	−19.821 (0.039)	−11.135 (0.336)
Observations	134	134	122	122	134	134	67	67	67	67	67	67

Notes: This table reports test results on the impact of ICT on the financial inclusion gap (made or received digital payments) in high- and low-income countries with the 12 static linear panel data models (Model 11.1–11.12). We chose one of the several static linear panel data models between pooled least square (PLS), random-effects (RE) model or fixed-effects (FE) model, with several tests. Finally, *, ** and ***denote statistical significance at the 10, 5 and 1% levels, respectively

Source: Created by authors



Notes: This graph reports test results on robustness by selecting observations randomly, with 85–98% of the observations without replacement. We repeat the baseline regression 250 times, producing coefficient values that form a normal distribution
Source: Created by authors

Figure 1. Robustness test 1 – the impact of variable of ICT and financial inclusion on economic growth

the total sample, the coefficient of the variable of interest weakens as the number of samples decreases, suggesting that country heterogeneity is hidden by the coefficient, aligning with the observations of Andrianaivo and Kpodar (2011).

An additional robustness test involved regression testing using Model 4.1 and 4.2 of Table 11 and Model 6.4 of Table 5 with 95% and 90% of the observation as shown in Table 12. Coefficient values for 95% and 90% of the observations are similar to the coefficient of the whole sample.

5. Conclusion

In this study, we examine the impacts of ICT on economic growth, FI on economic growth, the interaction variable of ICT and FI on economic growth, ICT on FI, and ICT on FI gaps based on the dynamic and the static panel model.

Although ICT significantly and positively influences economic growth in all countries, the ICT variable mobile broadband has no significant impact on economic growth in low-income countries, likely due to mobile broadband adoption not reaching critical mass. In contrast, no FI variable significantly impacts economic growth. Meanwhile, the ICT and FI interaction variables significantly and positively influence economic growth for only certain interaction variables.

Furthermore, this study's findings demonstrate that ICT variables significantly and positively impact FI. The differing results demonstrate a significant and positive sign for

Table 12. Robustness test 2 – the impact of variable of ICT and financial inclusion on economic growth

	Dependent variable: growth of GDP per capita (log)					
Independent variables	95% sample Model 4.1	90% sample Model 4.1	95% sample Model 4.2	90% sample Model 4.2	95% sample Model 6.4	90% sample Model 6.4
Lag of GDP	−0.102 (0.650)	−0.169 (0.539)	0.146 (0.440)	0.148 (0.502)	0.282 (0.879)	−0.100 (0.520)
Mobile broadband	−0.003 (0.983)	−0.084 (0.696)				
Internet			0.021*** (0.000)	0.023*** (0.000)	0.144*** (0.005)	0.160*** (0.002)
Deposits					0.295 (0.157)	0.379* (0.062)
Internet × Deposits					−0.020** (0.019)	−0.022*** (0.009)
Education	0.045 (0.087)	0.064* (0.071)	0.011** (0.024)	0.010** (0.048)	0.017* (0.055)	0.019** (0.017)
Industry	0.023 (0.357)	0.011 (0.704)	0.020* (0.057)	0.020* (0.075)	0.026 (0.155)	0.029* (0.062)
Service	0.029 (0.369)	0.005 (0.894)	0.024 (0.150)	0.024 (0.194)	0.034 (0.150)	0.025 (0.250)
Foreign direct investment	0.004 (0.616)	0.007 (0.376)	0.011** (0.030)	0.012** (0.012)	0.019 (0.085)	0.021* (0.050)
Trade openness	0.002 (0.387)	0.002 (0.447)	−0.000 (0.849)	−0.000 (0.466)	−0.011 (0.182)	−0.014* (0.072)
Work force	0.019 (0.148)	0.029 (0.065)	0.007 (0.211)	0.009 (0.154)	0.013 (0.163)	0.015 (0.101)
Constant	−1.987 (0.222)	−1.993 (0.241)	−0.078 0.929	−0.077 (0.932)	−2.165 (0.229)	−1.884 (0.266)
Observations	290	259	310	278	96	86
Arellano–Bond test	*p-val.* (AR) 1:0.547	*p-val.* (AR) 1:0.748	*p-val.* (AR) 1:0.159	*p-val.* (AR) 1:0.201	p value (AR) 1:0.305	*p* value (AR) 1:0.483
	p-val. (AR) 2:0.471	*p-val.* (AR) 2:0.843	*p-val.* (AR) 2:0.155	*p-val.* (AR) 2:0.231	*p* value (AR) 2:0.363	p value (AR) 2:0.359
Hansen J statistics	Prob. Chi^2: 0.042	Prob. Chi^2: 0.153	Prob. Chi^2: 0.030	Prob. Chi^2: 0.057	Prob. Chi^2: 0.033	Prob. Chi^2: 0.175

Notes: An additional robustness test involved regression testing using Model 4.1, Model 4.2 of Table 11 and Model 6.4 of Table 5 with 95% and 90% of the observation. We can see that coefficient values for 95% and 90% of the observations are similar to the coefficient of the whole sample
Source: Created by authors

banking branches in low-income countries but a significant and negative sign for high-income countries.

Another study's findings concern the diverse impact of ICT variables on the FI gap. Some ICT variables significantly reduce specific FI gaps in high-income countries but insignificantly reduce those gaps in low-income countries. The result in high-income countries implies that high-income countries tend to reduce the FI gaps successfully. Achieving a high-income level represents a prerequisite for effectively reducing FI gaps.

Furthermore, these findings can be important in understanding the role of integrated ICT and financial banking services, specifically for countries, in driving long-term economic growth. A country must reach a certain level for mobile broadband to influence economic growth. Then, a country must achieve a high-income level to reduce the FI gaps effectively.

Based on the test results in this research, the implementation of policies that need attention from the relevant authorities is as follows: ICT development in a country must be accompanied by a specific critical mass target so that it has an impact on the economy and prioritize mobile broadband development to minimize the FI gap.

This study is limited to certain ICT variables (mobile broadband and internet) and FI (deposits, credits, and mobile transactions) as the variables of interest. Therefore, further studies are needed to identify the other ICT and FI variables or create an index for those variables of interest.

Notes

1. Grouping into two groups (high- and low-income countries) comes from the simplification of four groups: upper-middle, high-income, lower-middle and low-income countries. The grouping of countries is based on data from the World Bank list of economies in July 2019 (World Bank, 2019), based on the gross national income (GNI) per capita (current USD) calculated using the Atlas method.
2. We add the options panels (hetero) and corr (psar1) based on the assumption that autocorrelation can differ between countries.

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