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FINANCIAL INCLUSION IN THE DIGITAL ERA: A KEY DRIVER FOR REDUCING INCOME INEQUALITY

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Abstract. Growing income inequality remains a pressing phenomenon in many developing economies, especially Sub-Saharan Africa (SSA), and may cause discontent in achieving inclusive growth which is crucial for sustainable development. Economies turning to financial inclusion as a critical component of economic development where access to formal financial institutions and services remains limited in the region. Digital technology has the potential to advance financial inclusion by tapping technology to extend financial access to underserved populations, as lack of access to efficient financial products and services can perpetuate income disparities. We employ a generalized quantile regression with an instrumental variables framework to investigate the distributional effects of financial inclusion and digitalization on income inequality in the region. Results imply that the use and adoption of the internet and mobile phones contribute to reducing income inequality, highlighting the transformative potential of digitalization across different quantiles. The findings indicate that public expenditure favors distributional impacts on inequality across quantiles. Our study suggests that policymakers in the region should prioritize the adoption and use of digital technology and foster an enabling policy that encourages the development of digital infrastructure and financial services to ensure widespread access and benefits for all segments of the population.

Keywords: digitalization, financial inclusion, income inequality, panel quantile regression.

JEL Classification: I16, O16, O30, O55.

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1. Introduction

Sub-Saharan Africa (SSA) observed fast-growing economic achievement over the recent decades despite the expectations that the growth would benefit every segment of the population. Currently, income inequality remains high in the SSA region indicating the wealthy segment of the population benefits more with the growth than the poor. Focus on the mitigation of income disparity within and among countries is among the Sustainable Development Goals (SDGs), financial inclusion is proposed to play a major role in developing inclusive growth and emerging economies (Kebede et al., 2023; Park & Mercado, 2018; Zhang & Posso, 2019). Inclusive finance attempts to remove the blockade that excludes individuals and businesses from engaging in the formal financial sector and using the products and services to better their lives by incorporating accessibility across a plethora of social constructs such as geographical region, socioeconomic standing, age, gender, or disability (International Monetary Fund, 2020; United Nations, 2020). Opportunities provided by financial inclusion

for marginalized and low-income individuals to access formal finances such as credit, saving, and insurance empower them with tools to invest in income-generating activities and manage their finances, thus financial inclusion helps lift people out of poverty and reduce disparities. Moreover, digital technology plays a significant role in advancing financial inclusion by simplifying access to financial services, which greatly contributes to digital inclusion and enables more individuals to participate in the digital economy.

The nexus between finances and income inequality changes the mainstream of macroeconomic thoughts. Policymakers loosen some development policies and frameworks to ensure inclusive growth and influence the ability of financial institutions on credit and loan provisions to control negative impacts on countries' income inequalities (International Monetary Fund, 2020). Accessibility, efficiency, and depth of financial services at the early stage of the country's development stage marginally increase income and profitable investments made by the poor population in entrepreneurial, health, education, and human capital activities improved (Brei et al., 2018; de Moraes & Cruz, 2023). Seven and Coskun (2016) argued that the poor and low-income population in emerging countries does not benefit from the promotion of economic growth with the accessibility of finance and found that financial institutions do not play a significant role in poverty reduction. Limited accessibility of financial services for the poor compared to other segments of the population might lead to the failure of income inequality reduction due to financial developments. However, the availability of financial services is acknowledged as a crucial mechanism for income distribution and the pace of economic growth as the imperfect financial market is a key poverty determinant in poverty and inequality models (Greenwood & Jovanovic, 1990; Seven & Coskun, 2016). In the long run, financial inclusion is found to impact the reduction of income inequality whereas inconclusive results in less inequality in countries with higher financial inclusion and acts as a buffer against increasing inequality as countries become richer (Thornton & Di Tommaso, 2020). Despite decades of rapid economic development and poverty reduction in the SSA region, more than half of global individuals projected will reside in the region by 2030, the largely poor population in developing regions still struggles to attain the minimum living standards and uneven progress on poverty reduction thus financial services moved up to the global reform's agenda with interest to lower inequality and break vicious poverty cycle (International Monetary Fund, 2020; United Nations, 2020).

The impact of financial inclusion in addition to digitalization on income inequality cannot be ignored. In developing countries, it remains a distant prospect the possibility that a large population enjoys affordable digital exposure due to the massive development of information technology. Reported that only 36 percent of the lower developing countries' population used the internet compared to global 66 percent in 2022 whereas 17 percent did not have access to mobile or fixed broadband networks (International Telecommunication Union, 2022, 2023). The accessibility and affordability of digital services are the barriers faced in the SSA region and may lead to hindering the income inequality of the region. The 2022 World Inequality Report (Chancel et al., 2022) shows significantly large wealth and income inequality where 52% of global income is held by the richest 10% of the global population. The top 10% capture 55.4% of 2021 national income in the SSA region compared to 58.6 in Latin America, 45.7% in North America, and 36 in Europe (Solt, 2020; UNU-WIDER, 2023). Despite efforts to reduce financial exclusion and reduce income inequality through digital finance initiatives in

the SSA countries, the impact on the most vulnerable and underserved populations remains limited. It is inherent to recognize the link between digitalization and financial inclusion confronted with the rigorous inequality situations, as well as to investigate fair income equality and inequality reduction due to full utilization of digitalization to narrow the gap in terms of inclusive growth and poverty reduction (Ahmed & Al-Roubaie, 2013).

The main objective of our paper is to investigate the distributional impacts of digitalization and financial inclusion on inequality in the SSA region. The study contributes to the body of literature in three strands. First, capture the impacts of demand- and supply-side indicators of inclusion on different quantiles of income distribution. We examine the accessibility and affordability of digital services in narrowing the distributional inequality gap and gain insights into the challenges and opportunities for leveraging digitalization to promote inclusive growth, reduce poverty, and foster more equitable income distribution. To our knowledge, most studies analyze the causal effect focusing on the average or mean effect which may seem unlikely that most countries obtain average or even close to average effect hence causing heterogeneity effect of finance and digital development not to be considered on reducing income inequality. Second, the study offers a novel methodological contribution, we investigate the entire distributional of causal effect by employing an instrumental variable generalized quantile regression approach where multiple endogenous and instrument variables are applied in the estimator (Powell, 2020). Third, inference of the dynamics of SSA region inequality provides a picture of disparate effects underlying the finance and digitalization in the region on different tails of inequality. The exact nature of the finance and digital development relationship remains inconclusive on inequality. The significance of this study lies in providing factual grounds for policy decisions aimed at fostering inclusive growth and lessening income inequality in SSA by examining the distributional impacts of financial inclusion and digitalization on income inequality across various quantiles. Understanding the nuanced relationship and intricate dynamics between these variables influences the designing of targeted interventions and policies that address income disparities and foster equitable economic development in the region. The paper is structured into the following sections: Section 1 introduction; Section 2 reviews the literature; Section 3 presents the data description and methodology adopted; Section 4 presents the results and discussion; and Section 5 concludes.

2. Literature review

2.1. Income inequality and financial inclusion nexus

Theoretically, the link was established on the finance-inequality nexus, the results of access and demand for financial products and services by a disproportionate population segment in society showed the persistence of income disparities. Concurrently, this leads to limited access to various opportunities due to the low capability of investment in human and physical capital. Income inequality is argued to be affected by financial inclusion by promoting investment in human capital through education and physical capital (Durlauf, 1996; Piketty, 1997). Access of poor and low-income individuals to financial services and products enhances them to save and borrow funds to invest in either entrepreneurial activities or human capital development which will either directly or indirectly affect income inequality in the short- or

long-term (Bresson, 2004). The direct effects of financial inclusion might be small on income distribution when the money is generated from the usage and accessibility of financial services and products. In the short term, it increases the income of individuals who benefit from accessing it. However, the indirect effect of financial inclusion prevails when poor or low-income individuals take advantage of their access to financial institutions and services to invest in human capital development so that they will have a better chance of becoming better entrepreneurs or securing better jobs due to their improved education and skills. In the long run, the expansion of economic opportunities will positively impact income distribution, as entrepreneurs generate more job opportunities and provide improved wages, therefore breaking down the vicious cycle of poverty and reducing inequality disparities. Greenwood and Jovanovic (1990) argued the nonlinear U-shaped on finance-inequality nexus. Access to finances is limited to a few individuals at the initial low level of economic development of an economy due to transaction and information costs, this will enhance higher income inequalities. The growing financial inclusion expands services and impacts individuals across different income groups leading to reducing income inequality.

Empirical studies concluded mixed results on the nexus. de Moraes and Cruz (2023) consider various banking qualities in examining the effect of the financial institution on the distribution of income and poverty reduction on a panel of low-income countries and emerging markets between 2000 and 2018 and found that relevance, availability, and efficiency of finance in reducing income inequality and poverty. Accessibility, efficiency, and large size of financial institutions provide a positive correlation on income inequality and poverty reduction as more financial services induce monetary welfare from deposits, savings, and credit to loans impacts income inequality. Financial inclusion demonstrate a favorable connection between financial institutions and alleviation of poverty, income inequality at early development stages is reduced due to increasing access to credit (Selim & Güngör, 2021; Zhang & Ben Naceur, 2019). The developing intermediation services pointed out that affect income distribution and stated the greater equality among society due to larger the size of the financial system. The liberalization of the financial sector often lead to a wider gap in poverty and inequality between countries, the poor and rich individuals in a society with the growth of financial institutions exerts a more pronounced influence than the financial market on poverty and income distribution (Brei et al., 2018; Jauch & Watzka, 2016; Omar & Inaba, 2020; Seven & Coskun, 2016).

The development of financial institutions and systems has a significant role in economic growth equalization and mitigating income inequality due to the increased global financial crisis, epidemic diseases, macroeconomic instabilities. Individuals with low credit, savings, and collateral histories are excluded from using and accessing financial products and services despite the lack of information parity (Kebede et al., 2023). Few individuals, households, or firms with better history benefit disproportionally from financial products such as credits and savings leading to increased income disparities in an economy. Moreover, it is necessary to consider the development of the financial sectors links with poverty and perpetuates the income inequality between different income groups, increasing the income gap. Therefore, we investigate the supply- and demand-side of the financial inclusion indicators on different quantiles of the SSA income inequality.

2.2. Digitalization on inequality-finance nexus

The digital revolution began early with automation and computerization in manufacturing, followed by the widespread usage of fixed telephones, mobile cellular phones, personal computers, and the Internet. The addition of new and advanced devices constantly improves accessibility and usage. During the initial phase of digitalization theories, the notion of the digital divide was frequently recognized as the perforation between individuals who have and who do not have access to information and communication technology (DiMaggio et al., 2004; Hsieh et al., 2008; Riggins & Dewan, 2005; Van Dijk, 2005). Digital technologies reduce transaction costs and time involved in accessing and exchanging information, and the easy availability of digital resources leads to a significant effect on growth through the functioning of markets and institutions. Riggins and Dewan (2005) argued that access to digital technology will bring individuals, households, communities, and businesses interaction that will result in improving standards of living and social welfare.

Focus on the first- and second-order effect of inequality in the ability to use and adopt the technology among individuals who have access and those who do not. The rise of the digital economy theoretically increases the income inequality gap and productivity growth spurred by the potential growth of advanced technologies. Advances in digital technologies boost productivity and growth, enhance innovation, and entrepreneurs hence better jobs to replace the old ones. Human capital accumulation improved and hence human welfare. Unfortunately, slow growth in adopting digital technologies in developing countries slows down productivity and inclusive growth due to low accessibility of the technology to more low-income individuals, geographic locations, job displacements, or gender. Hsieh et al. (2008) proposed different behavioral models isolating key factors that mainly impact two groups of individuals with and without access to cable internet. The tendency to respond to network exposure is observed to be higher for the advantageous individuals with confidence and enjoyment in using the available digital technology while the control of perceived behavior is more powerful in shaping digital use for the disadvantageous individuals. However, unequal access to digital technologies, such as internet connectivity and digital platforms, can create a digital divide that perpetuates income inequality. Individuals and communities with limited access to digital resources may be excluded from the benefits of digitalization, such as financial services and digital entrepreneurship, which can exacerbate income disparities.

Digitalization become a critical tool in addressing unequal development and prior studies do not reach a uniform conclusion on income inequality and digital advancement. Ali et al. (2019) pointed out that the affordability of information technology is positively associated with socioeconomic and income distribution. Faizah et al. (2021) found that digitalization has the potential to diminish income inequality and foster prosperity and inclusive development. Mora-Rivera and García-Mora (2021) studies income inequality between urban and rural areas in Mexico, it was suggested that the internet plays a role in decreasing poverty in rural regions. Digitalization was demonstrated to increase wealth inequality when its effect was investigated on wealth distribution using a panel of 45 developing and developed countries between 2000 and 2017 (Njangang et al., 2022). Yin and Choi (2023) argued the effect of digitalization on alleviating income inequality by exproling the digitalization effect for a panel of twenty countries from 2002 to 2018, heterogeneous impact of income level was observed,

and it was found that the interaction between trade openness, foreign direct investment, and digitalization can lead to a reduction in inequality. Prior studies attempted to investigate the digitalization effect while other determinants still merit improvement as the rich diversity of digitalization from micro to macro. Various literature studies the digitalization effect at the macro level as most studies focused on the micro level. Ascertained as among public policy objectives that transform economic development, technology transfer seems to be greatly beneficial for African economies development with relatively lower investment and development of infrastructural and human capital, transfer of technology and digitalization diffusion boost African living conditions (Kouladoum et al., 2023).

H1: *The relationship between financial inclusion and inequality is influenced by the presence and extent of digitalization.*

Theoretical and empirical studies have shown that the association between availability of financial service and inequality is not direct and can be modulated with other macroeconomic indicators. There is still much to be investigated on the inclusion-inequality nexus, digitalization growth is among the macroeconomic indicators that may contribute to decreased inequality in emerging and developing economies. The advancement of digital technologies may contribute to advance financial services and inclusive development, and part of its crucial benefit is its positive effect on reducing the financial exclusion gap. Several studies focused on relatively limited indicators, sample panels, and periods making it difficult to compare results across countries. The SSA region is a particularly important subject for our study as the region experiences low financial inclusion and digital divide than other regions. Given the rapid nature of technological penetration in the SSA, it can be argued that studies that used aggregate technology indicators should have a comparative advantage in identifying the effect of technological change on the relationship between income distribution and financial inclusion. Efforts to address income distribution in the digital age cannot be fully effective without ensuring wider financial inclusion gap. With the provision of access to digital tools and education, financial inclusion empowers individuals to participate in the digital economy, enhance their income-generating capabilities, and reduce the inequality gap between various segments of individuals in a society.

H2: *The influence of public expenditure affects the effect of digitalization and financial inclusion.*

However, empirical studies mainly focused on the development of finances on assessing the inequality nexus, there is a distinction between financial development and inclusion. Financial development focuses mainly on the growth and expansion of the financial sector in terms of the size and depth of financial markets, the availability of financial products and services, and the efficiency of financial intermediation whereas financial inclusion concerned with ensuring that individuals and businesses, particularly those who are marginalized or excluded from the formal financial sector, have access to and can use financial products and services to improve their economic well-being. Furthermore, financial inclusion primarily aims to address the involuntary exclusion from the formal financial sector that arises from factors such as discrimination, low income, and shortcomings in the financial market (Mialou et al., 2017; Pesqué-Cela et al., 2021). Our study is novel and will contribute to the existing body of

literature in various contexts. First, we investigate whether the adoption and use of digitalization have a heterogeneous effect on the relationship between finance and inequality in the SSA region. The digital era has brought about significant changes in the financial landscape, and investigating the effect of financial inclusion on income distribution within this context in the region and developing countries across different quantiles will indulge a deeper insight into the dynamics at play. Second, our study contributes to the literature on the nonlinearity of digitalization use on the financial-inequality nexus. Third, the impact of controlling public expenditure on reducing inequality. The study offers understanding into how financial inclusion and digitalization affect income inequality across various quantiles, identifying specific mechanisms and drivers that contribute to either reducing or exacerbating income disparities.

3. Data and methodology

3.1. Data description

In this study, we use two different datasets described as follows; nine indices provided by the Global Financial Development Index (GFDI) Database of the International Monetary Fund (IMF) are abstracted as panel A of supply-side indicators of financial inclusion including financial markets and institutions access, efficiency, and depth/size between 1997 and 2020. Panel B of demand-side indicators abstracted from the Financial Access Survey (FAS) database from 2004 to 2020 (International Monetary Fund, 2023). The Gini and Palma coefficient proxy income inequality measures abstracted from the World Income Inequality Database (WIID) (UNU-WIDER, 2023). The fixed telephone subscription, mobile cellular subscription per 100 people, and internet user as a percentage of the total population as a proxy for digitalization abstracted from ITU (International Telecommunication Union, 2022, 2023). The annual percentage of GDP per capita as a measure of economic growth, government expenditure per GDP, annual inflation, and trade as the sum of exports and imports per GDP as control variables abstracted from WDI (World Bank, n.d.). The variables in the study were selected as they attribute financial and digitalization toward sustainable development. Due to data availability, countries without required data for the study variables were not considered in the panels. The Appendix Figure A1 (a) presents the quantile of income inequality as a variable divided across the quantiles, (b) validate the assumption of quantiles from a standard normal distribution and the kernel plot of Appendix Figure A2 indicates that the distribution of income inequality is distinctly skewed and not normal.

We use the Gini and Palma indices to measure income inequality as the primary dependent variable and coefficient for the robustness check. Various studies considered the Gini coefficient as related to function distributional that includes the returns of factors of production while some studies considered the distribution of income that maps out the segments of a population into either owned assets or earned income. Our study captures the supply-side indicators of financial inclusion including financial markets and institution access, efficiency, and depth. Moreover, we considered the demand-side indicators including financial outreach and usage dimensions (Ahamed et al., 2021; Kebede et al., 2023). Digitalization comprises fixed telephone and mobile cellular subscriptions per 100 individuals, along with the percentage of the total population using the internet.

In line with various literature, we include control variables that have a potential link with key variables that are supported by both empirical and theoretical studies. Mixed outcomes concluded on the growth-inequality nexus whereas per capita GDP impacts income inequality either negatively, positively, or non-linearly (Kuznets, 1955; Seven & Coskun, 2016). Some studies show that the level of economic growth and development of an economy does not affect income inequality, whereas the U-shaped relationship of inequality is proposed at different stages of growth. However, trade openness proxied international trade as sum of exports and imports per GDP. The trade links our study's key variables to the rest of the global economy, trade openness disproportionately benefits more high- than low-income individuals in society, and thus it exacerbates income inequality (Amador & Cabral, 2017). Government funding on quasi-public goods and services has varying effects on income distribution, as it has the potential to benefit various segments of population. Government expenditure per GDP reduces income inequality and disproportionately benefits low-income individuals while exacerbating income distribution when unevenly allocated on development sectors that aim high-income individuals (Odusola, 2017). Inflation proxy overall macroeconomic stability plays a major role in income inequality, (Jackson, 2003; Meniago & Asongu, 2018) argued that inflation impacts income inequality differently among different groups within a country depending on individual sources of income, disproportionate and negative effects of inflation widen inequality in a lower- more than higher-income groups.

We utilize principal component analysis (PCA) to generate the composite measures of panel B. The initial phase of PCA constructs financial usage, encompassing the quantity of deposit accounts and depositors with commercial banks per 1000 adults, and domestic credit provided to the private sector by banks as a percentage of GDP. Financial outreach includes demographic and geographic penetration of financial institutions with the depth of ATMs and bank branches (per 100,000 adults and 1000 km^2). The second phase of PCA generates a financial inclusion utilizing the usage and outreach dimensions from the first phase, the index outlines approaches that enable financial services to be accessible, usable, and available to all members of a population. Ordinarily, when we employ PCA on a set of variables, we either want to use all or just some of the components. Using all variables creates orthogonal variables out of variables that are intercorrelated while using some of the variables reduces the number of degrees of freedom being used for the model (Jackson, 2003). Kaiser criterion was used to decide on the number of components to be selected, therefore the first principal components were selected.

3.2. Methodology

Prior to the main model inference, we employ the traditional QR approach with fixed effects that allow distributional conditioning of inequality on independent and control variables (Koenker, 2004; Koenker & Bassett, 1978; Machado & Santos Silva, 2019). The traditional QR approach assumes the relationship between outcome and dependent variables based on unnoticed factors. However, the inference of the estimated parameters confines significantly if unobserved variables become observed with the addition factors into the QR. The endogeneity problem failed to be controlled by the QR model, therefore, in this study we employ

the generalized quantile regression (GQR) with the instrumental variable framework which has several advantages over QR that was used in various prior studies (Powell, 2020). GQR splits the outcome variable into control and treatment variables while allowing conditioning of outcome variables on treatment and does not allow the conditional effect on the control variables. The QR model where τ^{th} conditional quantile of income inequality indicator formulated as:

$$Q\,gini_{it}\left(\tau / X_{it}^{'}\right)=\beta_i X_{it}^{'}+\varepsilon_{it},\ \tau\in\left(0,1\right), \tag{1}$$

where $Q\,gini_{it}\left(\tau / X_{it}^{'}\right)$ denote the Gini coefficient τ^{th} conditional quantile as linear function on countries $i=1,\ldots, N$ and time periods $t=1,\ldots, T$, $X_{it}^{'}$, ε_{it} and β_i are respectively vectors of explanatory variables, residual, and coefficient of explanatory variables. Displaying the average or mean relationship between covariates is one of the weaknesses in the linear functions analysis, implying that the linear method is allotted on the distribution of central tendency rather than including a different range of outcome variables. The ordinary least squares (OLS) model excludes countries with either lower or higher income inequality than medium countries that resulted in regression under or overestimation thus the fitted model distorts some important information and does not reflect reality (Sarkodie & Strezov, 2019).

Generally, GQR is considered an approach that enhances the counterfactual distributions for different quantiles of the outcome variable. The technique solves the endogeneity and nonlinearity relationship that exists between covariates with the assumption that the technique does not depend on average or mean effect regression estimates. The traditional QR approach assumes constant and smaller probability of the outcome variable than the quantile function across all control and instrument variables. However, GQR allows variation of this probability according to variables whereas some variables will indicate a high probability that the outcome being lower than the quantile function and a low probability predicted by other control variables. We employ GQR with fixed effect and instrumental variables framework to account for heterogenous covariates and unobserved heterogeneity effects, fixed effect included to control unobserved covariates in the estimation. The numerical optimization and adaptive Markov Chain Monte Carlo (MCMC) sampling were used to estimate the robustness of the model to cross-sectional dependency and stationarity (Byaro et al., 2023; Opoku & Aluko, 2021; Powell, 2020).

We divide data into different quantiles $\tau\in\left(0,1\right)$ on estimation process with a different number of algorithms runs and burns using MCMC simulation, the GQR instrumental variable framework was employed to explore the heterogeneous treatment impacts of finance and digital development on different quantiles of income inequality. The magnitude at a median indicates the country's performance at the 50th quantile relative to all other countries. With *F*, *DD*, and *Z* denoted financial inclusion, digitalization indicators, and control variables, our study models fitted as:

$$Q\,gini_{it}\left(\tau / F, DD, Z\right)=\sum_{i,t,k\subset R}\beta_{1k}F_{itk}+\sum_{i,t,l\subset R}\beta_{2l}DD_{itl}+\sum_{i,t,m\subset R}\beta_{3m}Z_{itm}+\varepsilon_{it.} \tag{2}$$

4. Empirical results and discussion

4.1. Quantile regression fixed-effect approach

Prior to the main model inference, we study the possible conditions by estimating conditional means through regression quantiles. The quantiles through moments approach offers insights into how the regressors affect the entire conditional distribution of income inequality. We employ QR with a fixed effect developed by Machado and Santos Silva (2019), the estimator provides inference on how selected variables affect the whole conditional distribution of inequality. The model is estimated with endogenous explanatory variables and individual effects via the method of moments, Table 1 presents results related to the QR fixed effect. It was observed that access, efficiency, and depth of financial market and development have positive and significant impacts on inequality in lower quantiles while financial institutions are insignificant across all quantiles. Moreover, it has been determined that financial usage and inclusion are significant and negative across all quantiles with less effect on upper quantiles than lower quantiles whereas financial outreach is not significant in lower quantiles. The preliminary results indicate that the adoption and use of the internet significantly decreases inequality across lower quantiles and fixed telephone subscription positively increases inequality with different significance levels across quantiles. Mobile cellular subscriptions have mixed results with either increased or decreased inequality across the quantiles. This result implies that countries exhibit higher inequality with a higher level of financial inclusion and digital connectivity, it has been contemplated that economic development and inflation insignificantly increase income inequality across quantiles whilst the positive and negative impact of government expenditure and trade openness. Public expenditure on quasi-services reveals lower impacts on inequality in countries with higher income distributions.

4.2. Main models results and discussion

Table 2 presents the GQR results related to the financial market dimension, results on simultaneous effects indicate that individuals who use the internet and mobile phones reduce inequality across all quantiles. However, fixed telephone subscriptions reduce inequality in lower quantiles and increase in upper quantiles. Access to the financial market reduces inequality in lower quantiles and increases in upper quantiles while efficiency and depth have a positive and significant impact on inequality across all quantiles. Table 3 shows that fixed and mobile phone subscriptions reduce inequality across all quantiles with the simultaneous impact of access, efficiency, and depth of financial institutions. Internet users significantly reduce inequality from 50^{th} to upper quantiles, the efficiency of the financial market significantly reduces inequality whereas depth is positive and significant across all quantiles while access to financial institutions shows a heterogenous impact on inequality. Moreover, inclusive growth as proxied by per capita GDP is not significant across all quantiles and shows significant positivity with access and depth of financial institutions in upper quantiles whereas government expenditure is positive and significant across all quantiles. Trade significantly increases income inequality on the median quantile while inflation decreases inequality in the upper quantiles.

Table 1. Quantile regression with fixed-effects model

Variables	25	50	75	25	50	75	25	50	75
Panel A:									
FM	10.78**	7.119	3.980						
	(4.243)	(6.919)	(11.96)						
FI				1.709	3.373	4.833			
				(6.446)	(4.684)	(6.496)			
FD							13.22**	10.34	7.996
							(5.932)	(20.07)	(34.97)
fts	0.447**	0.446	0.446	0.543***	0.487***	0.439**	0.502***	0.468	0.440
	(0.175)	(0.285)	(0.493)	(0.175)	(0.127)	(0.177)	(0.152)	(0.515)	(0.897)
mbs	–0.0158*	–0.0229	–0.0290	–0.0158	–0.0240***	–0.0312***	–0.0192**	–0.0258	–0.0311
	(0.00910)	(0.0148)	(0.0256)	(0.0101)	(0.00738)	(0.0102)	(0.00849)	(0.0287)	(0.0500)
internet	–0.0773***	–0.0452	–0.0177	–0.0724***	–0.0440**	–0.0191	–0.0775***	–0.0460	–0.0203
	(0.0268)	(0.0436)	(0.0753)	(0.0264)	(0.0193)	(0.0265)	(0.0232)	(0.0781)	(0.136)
Panel B:									
FO	–1.737	–1.583*	–1.408*						
	(1.522)	(0.928)	(0.790)						
FU				–1.643***	–1.284***	–0.914*			
				(0.404)	(0.339)	(0.505)			
FII							–2.183***	–1.847***	–1.504**
							(0.526)	(0.438)	(0.645)
fts	0.699	0.649**	0.591**	0.868***	0.816***	0.762***	0.811***	0.750***	0.688***
	(0.492)	(0.300)	(0.255)	(0.199)	(0.166)	(0.249)	(0.182)	(0.151)	(0.223)
mbs	0.00543	–0.00198	–0.0104	0.00667	–0.00206	–0.0111	0.00845	–7.30e-05	–0.00877
	(0.0151)	(0.00926)	(0.00789)	(0.00574)	(0.00485)	(0.00718)	(0.00572)	(0.00485)	(0.00704)
internet	–0.0634*	–0.0445**	–0.0230	–0.0388***	–0.0295***	–0.0199	–0.0442***	–0.0308***	–0.0170
	(0.0363)	(0.0223)	(0.0190)	(0.0121)	(0.0101)	(0.0151)	(0.0130)	(0.0108)	(0.0159)
gdp	0.0528	0.0384	0.0221	0.0302	0.0309	0.0317	0.0353	0.0301	0.0247
	(0.0707)	(0.0431)	(0.0367)	(0.0259)	(0.0216)	(0.0323)	(0.0255)	(0.0211)	(0.0312)
gce	0.160	0.128**	0.0918*	0.167***	0.141***	0.115**	0.158***	0.127***	0.0967**
	(0.0987)	(0.0604)	(0.0515)	(0.0410)	(0.0342)	(0.0511)	(0.0381)	(0.0318)	(0.0468)
infla	0.0413	0.0463	0.0519	0.0339	0.0394	0.0451	0.0384	0.0423*	0.0463
	(0.0838)	(0.0510)	(0.0434)	(0.0314)	(0.0261)	(0.0391)	(0.0299)	(0.0247)	(0.0366)
trade	–0.0346	–0.0372**	–0.0402***	–0.0377***	–0.0420***	–0.0465***	–0.0354***	–0.0397***	–0.0441***
	(0.0291)	(0.0177)	(0.0151)	(0.0111)	(0.00924)	(0.0138)	(0.0107)	(0.00888)	(0.0131)

Note: Standard errors presented in parentheses; ***, **, * significant at 0.01, 0.05, 0.1 Level of significance: FM, FI, FD denoted composite indicators of financial markets, institutions, and development as supply side dimension; FO, FU, and FII denoted PCA indices of financial outreach, usage and inclusion as demand-side dimension.

We employ the model in the demand-side indicators of financial inclusion, Table 4 presents the results related to financial outreach indicators, the geographical location of the number of commercial bank branches and ATMs per 1000 km^2 significantly reduces income inequality across all quantiles whereas the demographic dimension including the number of ATMs significantly increases inequality across all quantiles while significantly bank branches

per 100,000 adults reduce at lower and upper quantiles and slightly significant at 50th quantile. Accessibility of internet connectivity significantly reduces inequality with available ATMs and insignificantly with the bank branches, whilst mobile cellular subscription significantly reduces lower quantiles of inequality with the geographical location of ATMs and bank branches respectively by 0.0285 and 0.0347. Mobile subscription reduces lower and upper quantiles of inequality significantly with the number of ATMs by 0.0330 and 0.0167 respectively. Fixed telephone subscriptions increase inequality with geographical coverability of ATMs on lower and upper quantiles while across all quantiles with bank branches.

Table 5 presents the financial usage indicators including the number of deposit accounts with commercial banks per 1,000 adults significantly increases inequality in the lower and upper quantiles while the number of depositors per 1,000 adults with commercial banks significantly increases inequality in the 50th quantile. The ratio of provided domestic credit to the private sector by banks and GDP significantly raise inequality across different quantiles with a higher coefficient in the lower quantile. Internet significantly reduces inequality with the provision of credit and the number of deposit accounts while significant across all quantiles with the number of depositors. The results imply that internet usage anhavedoption has a higher impact on reducing inequality to higher quantiles than lower quantiles on depositing funds into commercial banks. The telephone subscriptions significantly reduce inequality across all quantiles on all dimensions while mobile cellular subscription significantly reduces inequality on lower quantiles.

Table 2. Financial market dimension estimation results

Variables	Quantiles											
	25	50	75	25	50	75	25	50	75	25	50	75
FMA	–6.898***	5.732	8.879***							–5.476***	4.254***	3.754***
	(1.388)	(4.750)	(1.825)							(1.373)	(0.493)	(0.658)
FME				10.59***	20.13**	20.83***				10.86***	7.200***	4.468***
				(0.220)	(9.908)	(3.398)				(0.409)	(0.144)	(0.238)
FMD							25.01***	21.15***	16.78***	23.03***	18.26***	12.44***
							(2.244)	(1.367)	(1.276)	(0.483)	(0.873)	(0.240)
fts	–0.166***	–0.274*	–0.0388	–0.236***	0.129	–0.0432	–0.392***	–0.274***	0.0544	–0.320***	–0.428***	0.0402***
	(0.0259)	(0.157)	(0.0251)	(0.0137)	(0.281)	(0.0959)	(0.0280)	(0.0616)	(0.0555)	(0.0250)	(0.0109)	(0.00824)
mbs	–0.0336**	–0.0163	0.00465	–0.0356***	–0.0649	–0.00590	–0.0366***	0.00284	–0.00667	–0.0356***	–0.00110	–0.0150***
	(0.0134)	(0.0166)	(0.00594)	(0.00543)	(0.0427)	(0.0112)	(0.00498)	(0.00797)	(0.00447)	(0.00494)	(0.00354)	(0.00266)
internet	–0.00816	–0.0186	–0.0440**	–0.0210	–0.0408	–0.0406	–0.0194	–0.116***	–0.0864***	–0.0330**	–0.0856***	–0.0559***
	(0.0549)	(0.0430)	(0.0195)	(0.0138)	(0.0311)	(0.0270)	(0.0248)	(0.0183)	(0.0122)	(0.0142)	(0.00843)	(0.00608)
gdp	0.0359	0.0881	–0.0655	0.00651	0.722	–0.0354	–0.123	0.150	0.219	–0.0358	0.0872	–0.0528
	(0.0697)	(0.288)	(0.110)	(0.0247)	(0.485)	(0.245)	(0.178)	(0.0959)	(0.237)	(0.0352)	(0.119)	(0.0480)
gce	0.187**	–0.405	0.286***	0.237***	–2.069	0.292**	0.211**	0.603***	0.304***	0.123***	0.197***	0.230***
	(0.0773)	(0.419)	(0.0588)	(0.0174)	(1.589)	(0.117)	(0.0895)	(0.213)	(0.0479)	(0.0244)	(0.0212)	(0.0163)
infla	0.0264**	–0.00713	–0.0144	0.00928***	–0.348	0.0174	0.00201	0.0171*	–0.0443	0.00740***	0.00677*	–0.00557**
	(0.0104)	(0.0269)	(0.0205)	(0.00177)	(0.238)	(0.0486)	(0.0135)	(0.00965)	(0.0623)	(0.00173)	(0.00408)	(0.00250)
trade	0.0531***	0.0556**	–0.00457	0.0142***	0.243	–0.00111	0.0120	–0.0516	0.00350	0.0119	0.0159***	–0.00329
	(0.0151)	(0.0281)	(0.00951)	(0.00169)	(0.162)	(0.0160)	(0.0106)	(0.0369)	(0.0216)	(0.00722)	(0.00530)	(0.00270)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

Table 3. Financial institutions dimension estimation results

Variables	Quantiles											
	25	50	75	25	50	75	25	50	75	25	50	75
FIA	−10.93*	6.545	7.593*							−13.22***	5.080*	8.049***
	(5.650)	(4.038)	(4.595)							(4.048)	(2.643)	(1.024)
FIE				−2.784	−3.090	−3.825*				−3.842*	−3.627***	−5.603***
				(4.226)	(2.329)	(2.056)				(1.974)	(0.682)	(0.913)
FID							17.77***	16.36***	18.48***	22.58***	20.72***	18.25***
							(0.530)	(3.553)	(0.619)	(1.548)	(0.810)	(0.493)
fts	−0.0649	−0.306***	0.120	0.0805	−0.213***	−0.00363	−0.371***	−0.0548	−0.302***	−0.212***	−0.397***	−0.308***
	(0.0879)	(0.0553)	(0.209)	(0.325)	(0.0464)	(0.0437)	(0.0269)	(0.376)	(0.0430)	(0.0266)	(0.0578)	(0.0189)
mbs	−0.0301***	0.00509	0.00750	0.00211	0.00680	0.00129	−0.0406***	−0.0266	−0.0167***	−0.0365***	−0.0140***	−0.0123**
	(0.00829)	(0.00599)	(0.00850)	(0.0452)	(0.00647)	(0.00729)	(0.00920)	(0.0200)	(0.00584)	(0.00672)	(0.00321)	(0.00508)
internet	−0.0200	−0.0652**	−0.0953**	−0.0781	−0.0634**	−0.0196	−0.0348	−0.0375	−0.0431**	−0.00128	−0.0785***	−0.0993***
	(0.0220)	(0.0263)	(0.0395)	(0.110)	(0.0296)	(0.0323)	(0.0238)	(0.0307)	(0.0186)	(0.0272)	(0.00985)	(0.00930)
gdp	0.115	−0.0147	0.737*	−1.719	0.265	−0.0703	0.0508	0.640	0.0924*	−0.119	0.0195	0.00424
	(0.158)	(0.0931)	(0.427)	(1.726)	(0.439)	(0.234)	(0.109)	(0.778)	(0.0510)	(0.229)	(0.0687)	(0.0361)
gce	−0.0230	0.224***	0.583***	0.534	0.166	0.508***	0.0747	0.360	0.180*	0.245***	0.146**	0.162***
	(0.238)	(0.0745)	(0.115)	(0.393)	(0.201)	(0.138)	(0.156)	(0.319)	(0.0923)	(0.0907)	(0.0653)	(0.0115)
infla	0.0408*	0.0127	0.0418	−0.0577	−0.00632	0.00751	0.00762	0.0666	0.00133	−0.000337	0.00443	−0.00539**
	(0.0227)	(0.0227)	(0.0315)	(0.0584)	(0.0233)	(0.0454)	(0.00536)	(0.0939)	(0.00997)	(0.0114)	(0.00339)	(0.00271)
trade	0.0516**	−0.0141	0.00746	−0.0494	0.0154	−0.00566	0.0422	0.130	0.00252	0.0102	0.0162*	−0.00594
	(0.0221)	(0.0228)	(0.0174)	(0.0741)	(0.0373)	(0.00951)	(0.0292)	(0.153)	(0.0116)	(0.0200)	(0.00928)	(0.00469)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

Table 4. Financial outreach estimation results

Variables	Quantiles											
	25	50	75	25	50	75	25	50	75	25	50	75
atm_1000	−0.0671***	−0.0708**	−0.0815***									
	(0.00932)	(0.0312)	(0.0258)									
atm_100000				0.116***	0.116***	0.104***						
				(0.0317)	(0.0402)	(0.0193)						
bank_1000							−0.321***	−0.243***	−0.194***			
							(0.0377)	(0.0306)	(0.0196)			
bank_100000										−0.257***	−0.523	−0.236***
										(0.0518)	(0.439)	(0.0403)
fts	0.241**	0.276	0.332**	−0.288***	−0.292*	−0.382***	0.721***	0.504***	0.351***	−0.0256	−0.0803	−0.143***
	(0.0938)	(0.250)	(0.151)	(0.0348)	(0.153)	(0.0225)	(0.0919)	(0.0784)	(0.0738)	(0.0263)	(0.0521)	(0.0533)
mbs	−0.0285***	−0.00966	−0.00766	−0.0330**	−0.0302	−0.0167***	−0.0347***	−0.0318	−0.00160	−0.0138	0.0177	−0.00547
	(0.00658)	(0.0263)	(0.00974)	(0.0137)	(0.0211)	(0.00581)	(0.00817)	(0.0288)	(0.0126)	(0.0116)	(0.0111)	(0.00731)
internet	−0.0199***	−0.0791**	−0.0613	−0.0662***	−0.0799	−0.0539***	−0.00152	−0.0183	−0.0510	−0.0343	0.00276	0.0118
	(0.00661)	(0.0350)	(0.0509)	(0.0193)	(0.0878)	(0.0152)	(0.0248)	(0.0578)	(0.0353)	(0.0404)	(0.124)	(0.0184)
gdp	0.0545	0.0327	0.143	0.350*	0.194	0.0390	0.297	0.329	0.193	0.101	−1.354	0.0933
	(0.0873)	(0.202)	(0.295)	(0.203)	(0.573)	(0.0627)	(0.217)	(0.379)	(0.129)	(0.0971)	(1.731)	(0.185)
gce	0.224***	0.412***	0.248***	0.332***	0.439***	0.275***	0.129***	0.358**	0.327***	0.292***	−0.445	0.399***
	(0.0506)	(0.154)	(0.0822)	(0.0872)	(0.169)	(0.0587)	(0.0441)	(0.150)	(0.0821)	(0.0965)	(0.913)	(0.0537)
infla	−0.139	−0.129	−0.000221	−0.269***	−0.0639	−0.0628	−0.210	−0.111	0.00558	−0.229***	−1.388	0.132
	(0.191)	(0.159)	(0.143)	(0.0280)	(0.433)	(0.0931)	(0.154)	(0.103)	(0.0574)	(0.0607)	(1.674)	(0.115)
trade	−0.0645***	−0.0526	−0.0210	−0.0477***	−0.00934	−0.0319***	−0.0117	−0.0763	−0.0542**	−0.0114	−0.0193	0.00335
	(0.0185)	(0.0402)	(0.0150)	(0.0135)	(0.0532)	(0.00314)	(0.0335)	(0.0565)	(0.0224)	(0.0194)	(0.0286)	(0.0123)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

Table 5. Financial usage estimation results

Variables	Quantiles								
	25	50	75	25	50	75	25	50	75
deposit	0.00329**	0.00143	0.000863***						
	(0.00159)	(0.00222)	(0.000224)						
depositor				–0.000713	0.00276**	0.000718			
				(0.000834)	(0.00139)	(0.00113)			
credit							0.141***	0.0867***	0.0666***
							(0.0134)	(0.0270)	(0.0180)
fts	–0.352***	–0.251**	–0.343***	–0.0558	–0.224***	–0.118*	–0.523***	–0.355***	–0.320***
	(0.116)	(0.106)	(0.0144)	(0.0516)	(0.0457)	(0.0646)	(0.0373)	(0.0707)	(0.0422)
mbs	–0.0356**	0.00852	0.0202***	–0.00929	0.0174***	0.0153*	–0.0742***	–0.0272	–0.0179
	(0.0157)	(0.00988)	(0.00574)	(0.00870)	(0.00514)	(0.00885)	(0.00479)	(0.0312)	(0.0164)
internet	0.0114	–0.0747	–0.0804***	–0.0814***	–0.129***	–0.137***	0.0108	–0.0608	–0.0745*
	(0.0380)	(0.0500)	(0.00954)	(0.0153)	(0.0178)	(0.0265)	(0.0193)	(0.0550)	(0.0448)
gdp	0.296**	–0.141	0.0995***	0.143**	0.160*	0.0169	0.278**	–0.390	–0.143
	(0.149)	(0.424)	(0.0335)	(0.0672)	(0.0821)	(0.0435)	(0.112)	(0.446)	(0.355)
gce	0.288***	0.389***	0.365***	0.434***	0.227***	0.485***	0.0934*	0.236***	0.350***
	(0.0489)	(0.120)	(0.0100)	(0.0684)	(0.0752)	(0.0293)	(0.0510)	(0.0566)	(0.0535)
infla	–0.151**	0.251	–0.0460***	–0.312***	–0.182	0.104	–0.172***	–0.251	0.0783
	(0.0763)	(0.327)	(0.0111)	(0.0454)	(0.126)	(0.0965)	(0.0612)	(0.179)	(0.0952)
trade	–0.0584***	–0.0500**	–0.0594***	–0.0828***	–0.0106	–0.0686***	0.0255**	–0.0133	–0.0177
	(0.00877)	(0.0215)	(0.00412)	(0.0159)	(0.0224)	(0.0101)	(0.0105)	(0.0253)	(0.0269)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

4.3. Composite indicator of financial inclusion

Table 6 presents the supply-side composite indicator of financial inclusion. Financial development and institutions are significant and positive in lower and upper quantiles while financial markets significantly increase inequality only in the upper quantile. Mobile subscriptions reduced inequality with financial markets across all quantiles while the internet significantly reduced inequality on lower quantiles and fixed telephone subscriptions at the 50th quantile. Table 7 presents the results of the demand-side composite indicator of financial outreach, usage, and inclusion. Financial outreach is significant and negative from the 50th to upper quantiles while financial usage and inclusion are positive. Digitalization reduces inequality with financial usage and inclusion, fixed telephone is positive while the internet and mobile phone subscriptions are negative with financial usage. The results indicate that accessibility of financial institutions and markets reduces inequality at lower quantiles. However, the efficiency and depth of financial institutions show a heterogenous impact on inequality across all quantiles while market dimensions significantly increase income inequality. The composite index of financial inclusion for both demand- and supply-side indicators significantly increases income inequality and results are not in line with that of Kebede et al. (2023). We rejected the null hypothesis, results indicated that the use and adoption of digitalization enhance the financial inclusion gap to be lowered between the rich and poor individuals in the region. We do not reject the null hypothesis that the impact of financial inclusion on income inequality depends on digitalization.

Table 6. Supply-side composite indicators of financial inclusion

Variables	Financial market			Financial institutions			Financial development		
	25	50	75	25	50	75	25	50	75
FM	0.107	16.02	23.41***						
	(29.83)	(12.37)	(1.259)						
FI				27.90***	10.88	28.63***			
				(1.117)	(18.22)	(2.327)			
FD							30.26***	7.757	31.80***
							(2.908)	(51.77)	(1.022)
fts	–0.0976	–0.281**	–0.0555	–0.514***	0.317	–0.485***	–0.501***	–0.355	–0.447***
	(0.372)	(0.131)	(0.0679)	(0.0247)	(0.970)	(0.0580)	(0.0292)	(0.310)	(0.0669)
mbs	–0.0209**	–0.0113*	–0.0144*	–0.0439***	–0.0268	–0.0266**	–0.0410***	–0.00215	–0.0259***
	(0.00912)	(0.00608)	(0.00868)	(0.00532)	(0.0238)	(0.0119)	(0.00674)	(0.0291)	(0.00526)
internet	–0.0528*	–0.0372	–0.0305	–0.0511***	–0.0113	–0.0746**	–0.0355**	0.0291	–0.0656***
	(0.0299)	(0.0249)	(0.0262)	(0.0151)	(0.0784)	(0.0321)	(0.0144)	(0.198)	(0.0155)
gdp	0.247	0.252*	–0.165	0.213*	–1.038	0.178	–0.0600	–2.235	–0.139**
	(0.327)	(0.131)	(0.121)	(0.116)	(1.193)	(0.329)	(0.0767)	(4.594)	(0.0540)
gce	–0.519	0.593**	0.251***	0.113***	0.0661	0.0186	0.129**	1.198	0.137***
	(0.840)	(0.301)	(0.0631)	(0.0181)	(0.0987)	(0.0814)	(0.0596)	(2.221)	(0.0402)
infla	–0.0399	0.0280*	–0.00526	–0.0309	–0.170	–0.0250	0.0161	0.567	–0.0151
	(0.0502)	(0.0165)	(0.00765)	(0.0261)	(0.211)	(0.0348)	(0.0127)	(1.154)	(0.0105)
trade	–0.0180	0.0460	0.00285	0.0371	0.202	–0.00978	0.0366	0.357	–0.00216
	(0.0442)	(0.0662)	(0.0145)	(0.0254)	(0.196)	(0.0229)	(0.0229)	(0.703)	(0.00834)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

Table 7. Demand-side composite indicators of financial inclusion

Variables	outreach			usage			financial inclusion		
	25	50	75	25	50	75	25	50	75
FO	–1.498	–2.295***	–1.918***						
	(0.975)	(0.730)	(0.479)						
FU				2.482***	2.449***	1.450***			
				(0.359)	(0.782)	(0.156)			
FII							1.778***	0.471	0.880***
							(0.471)	(0.955)	(0.215)
fts	0.173	0.268*	0.184	–0.574***	–0.545***	–0.418***	–0.394***	–0.192	–0.365***
	(0.216)	(0.154)	(0.129)	(0.0764)	(0.163)	(0.0308)	(0.0835)	(0.158)	(0.0226)
mbs	–0.0528***	0.0218**	–0.00103	–0.0475***	–0.0144*	–0.00165	–0.0334**	–0.0206	–0.000683
	(0.00996)	(0.00945)	(0.0150)	(0.0118)	(0.00828)	(0.00654)	(0.0152)	(0.0144)	(0.00609)
internet	–0.0244	–0.0906***	–0.0176	–0.0713***	–0.143***	–0.157***	–0.102**	–0.0876**	–0.104***
	(0.0209)	(0.0188)	(0.0529)	(0.0273)	(0.0214)	(0.0152)	(0.0423)	(0.0349)	(0.0313)

End of Table 7

Variables	outreach			usage			financial inclusion		
	25	50	75	25	50	75	25	50	75
gdp	0.00817	–0.0857	0.0620	–0.0830	–0.00973	0.0751*	–0.148	0.277*	–0.0221
	(0.0796)	(0.160)	(0.0663)	(0.202)	(0.206)	(0.0428)	(0.120)	(0.154)	(0.0616)
gce	0.118***	0.166	0.362***	0.0642	0.293***	0.342***	0.173***	0.410***	0.334***
	(0.0417)	(0.138)	(0.0594)	(0.0803)	(0.0908)	(0.0420)	(0.0552)	(0.107)	(0.0439)
infla	–0.276**	–0.00725	–0.137	–0.247	–0.0995**	–0.0384	–0.413***	0.140	–0.0215
	(0.115)	(0.0751)	(0.0889)	(0.198)	(0.0445)	(0.0537)	(0.154)	(0.125)	(0.0510)
trade	0.0324*	0.00132	–0.00107	0.0278	0.00954	–0.0199***	0.0143	–0.0683*	–0.0326***
	(0.0176)	(0.00946)	(0.0262)	(0.0225)	(0.0491)	(0.00535)	(0.0251)	(0.0409)	(0.00909)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01: The algorithm optimizes MCMC with 1000 draws, 300 burn-in, 0.5 acceptance rate. Control and independent variables as instrumental variables. Only control variables as proneness variables. Time fixed-effects included.

4.4. Does the impact of digitalization and financial inclusion depend on government expenditure?

The SSA region experiences an increasing digital divide gap due to demographic and geographical barriers that limit the accessibility of financial products and services that influence the increasing income disparity gap. Results imply that digitalization favors the distributional impact of financial inclusion on different quantiles of income inequality. Therefore, do not reject the null hypothesis that the limited accessibility and affordable financial and digital services in the SSA region contribute positively to reducing income inequality. Better access to credit is triggered due to transparent economic agents and financial products and services expected to be available to excluded segments of the population due to the availability of phones and internet connectivity. Over the past two decades, economic growth trends in the region have shown a mix of progress and challenges, there has been gradual development in many economies. With greater economic resources, governments and financial institutions can invest in building financial infrastructure, expanding access to banking services, and developing digital financial solutions. We hypothesize that the effect of digitalization and financial inclusion depends on government expenditure on decreasing income disparity in the region. While government expenditure can play a crucial role by reducing information asymmetry within a country by investing in infrastructures that can enhance financial inclusion. Our results indicate that government expenditure increases income inequality in the SSA economies despite the negative impacts of digitalization. Expenditure can be allocated towards developing, building, and improving the necessary digital infrastructure, such as broadband networks and mobile connectivity. Infrastructure investments and developments are essential for expanding availability of digital services, especially in underserved and rural areas as the digital developments will foster integrations to financial services and products.

4.5. Robustness and sensitivity check

We use the Palma coefficient as an alternative measure of income inequality for a robustness and sensitivity check. The Palma coefficient specifically examines the income distribution between the bottom 40% and top 10% of earners. This focus on the extremes of the income distribution provides a different perspective compared to the Gini coefficient, which considers the entire income distribution. Table 8 presents robustness results using the Palma ratio, significance of the results is in line with that of the main models i.e., the significance of financial usage, outreach, market, and institutions with digitalization are the same as in our main results models across different quantiles. Government expenditure and trade openness are significant whereas GDP and inflation are slightly significant across the different quantiles. Table A3 presents results related to composite indices, financial inclusion is insignificant and negative on the 75^{th} quantile which is the only difference from the main results. With the problem of endogeneity arising in the panel data, we also employ the instrumental variable generalized method of moment (IV/GMM). Table A1 and Table A2 respectively present the results related to IV/GMM of supply and demand-side indicators of financial inclusion. Significant results imply financial and digitalization development positively reduces income inequality and hence suggests the validity of our study findings in the SSA region. We employ structural quantile function estimation with the instrumental variable framework (SQF-IV) defined by (Chernozhukov & Hansen, 2008), Table A4 presents results related to SQF-IV. Internet and mobile subscriptions are negative and significant across different quantiles, and have a low impact on upper quantiles with supply-side indicators and while lower impact on low quantiles with supply-side indicators. Financial outreach is significantly negative across different quantiles whereas financial market, institution, and development are significant positive.

5. Conclusions

Reducing income inequality within and across countries is among the aims of SDGs, increasing easy accessibility of financial services and products becomes a policy priority to improve inclusive growth and achieve sustainable economic development. Digitalization plays a significant role in reducing the financial exclusion gap between lower- and higher-income individuals in a society. Theoretical and empirical outcomes related to the relationship between financial inclusion and income inequality are controversial, little is known concerning the digitalization impact on the inclusion-inequality nexus in the SSA region. Digitalization is more powerful in transforming and reinforcing real-time financial services through the internet and mobile applications that enhance income distributions. Extended financial services can provide easy access and flow of income from physical locations of financial institutions and markets through technology growth, access to broadband, and the internet via distant customers. Moreover, financial services can be provided before customers reach financial institutions physically through web consultation and registration. The rapid information expansion and sharing in both rural and urban through mobile phones and advanced other internet application technologies allow financial services to be accessed on time through network creation.

Table 8. GQR Robustness results (Palma ratio)

Variables	Financial market			Financial institution			Financial outreach			Financial usage		
	25	50	75	25	50	75	25	50	75	25	50	75
Access	−1.611***	1.314***	1.929***	−2.224***	2.123***	0.906						
	(0.616)	(0.159)	(0.144)	(0.534)	(0.747)	(0.707)						
Efficiency	3.922***	2.719***	2.355***	−1.405***	−1.698***	−1.272***						
	(0.192)	(0.152)	(0.253)	(0.220)	(0.465)	(0.385)						
Depth	6.054***	7.537***	6.380***	6.358***	8.039***	9.309***						
	(0.602)	(0.402)	(0.148)	(0.219)	(0.459)	(0.308)						
atm_1000							−0.0310***	−0.0273***	−0.0355***			
							(0.00159)	(0.00754)	(0.0109)			
atm_100000							0.0503***	0.0424***	0.0822***			
							(0.00130)	(0.00503)	(0.0133)			
bank_1000							0.0138***	0.0188	0.0280			
							(0.00276)	(0.0185)	(0.0223)			
bank_100000							−0.151***	−0.148***	−0.196***			
							(0.00764)	(0.0237)	(0.0331)			
deposit										0.00333***	0.000362	−0.00194***
										(0.000187)	(0.000378)	(0.000207)
depositor										−0.00234***	−0.000999**	−0.000366***
										(0.000248)	(0.000432)	(0.000133)
credit										0.0635***	0.0629***	0.0520***
										(0.00352)	(0.00555)	(0.00182)
fts	−0.0874***	−0.133***	0.0149***	−0.0792***	−0.133***	−0.0950***	0.133***	0.0952***	0.0879***	−0.244***	−0.122***	−0.104***
	(0.0111)	(0.00449)	(0.00568)	(0.00515)	(0.0124)	(0.0116)	(0.00639)	(0.0172)	(0.00699)	(0.00812)	(0.0163)	(0.00282)
mbs	−0.00915***	4.25e-05	−0.00512***	−0.0112***	−0.00767***	−0.00494**	−0.0123***	0.00225	−0.0147***	−0.0149***	0.00164	0.00233***
	(0.00174)	(0.000997)	(0.00135)	(0.000586)	(0.00196)	(0.00226)	(0.000721)	(0.00215)	(0.00186)	(0.00131)	(0.00309)	(0.000861)
internet	−0.00452	−0.0277***	−0.0262***	0.00712***	−0.0103*	−0.0328***	0.00429	−0.0209***	0.0106***	−0.0172***	−0.0293***	0.0239***
	(0.00397)	(0.00418)	(0.00556)	(0.00256)	(0.00578)	(0.00554)	(0.00336)	(0.00731)	(0.00366)	(0.00656)	(0.00750)	(0.00318)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01.

We employ Powell's (2020) GQR estimator to investigate the distributional impacts of digitalization and financial inclusion on different quantiles of income inequality. We capture the effect of both demand- and supply-side indicators of financial inclusion and two-stage PCA used to develop indices of financial outreach, usage, and inclusion. Our main result indicates that financial outreach reduces inequality across all quantiles. We found that the geographical indicator of the number of ATMs and commercial bank branches reduces the income distribution gap while the demographic dimension indicator of bank branches reduces while the number of ATMs increases inequality across all quantiles. The efficiency of financial institutions reduces inequality whereas the overall index of financial inclusion with effects of digitalization increases inequality in the region. Moreover, results indicate that digitalization significantly reduces income inequality with financial inclusion across different quantiles. Subscription of mobile, fixed telephone technology, and internet adoption and use on accessing financial services among individuals' lower income inequality reduce inequality. Furthermore, the effectiveness and advancement of technology for financial institutions are mechanisms to lower inequality. The findings also reveal heterogeneous impacts on income inequality and outcomes vary across different quantiles. Overall results support the idea of increasing adoption, penetration, and use of digitalization contributing to income inequality reduction and expected to reduce poverty in the SSA region to achieve inclusive growth and sustain-

able development goals. We assessed whether the distributional impact of digitalization and financial inclusion depends on government expenditure, the outcome showed government expenditure in development investment impacts inequality across different quantiles. More research is needed to better understand income inequality asymmetric relationships with financial and digitalization development. Future research with country-specific and public expenditure on different development sectors is required.

Our results demonstrated to be robust to various sensitivity analyses concerning the impact of digitalization on the finance-inequality nexus, we employ SQF-IV and IV/GMM to address the endogeneity problem that may arise in panel data and use the Palma coefficient as a different measure of income inequality. The findings suggest several policy implications and proactive steps can be taken by policymakers to enrich financial inclusion, foster inclusive growth, reduce income inequality, and facilitate progress towards SDGs in the region. Prioritize initiatives that promote the establishment of physical bank branches and digital financial service providers in underserved areas. This involves incentivizing financial institutions to extend their reach to remote regions and supporting the development of agent banking networks and electronic money platforms that enable convenient and affordable financial transactions. Develop inclusive regulatory frameworks that balance consumer protection and innovation by equipping individuals with the necessary digital skills and taking advantage of available financial services. The regulations should be flexible enough to accommodate new financial technologies and business models while ensuring adequate safeguards. Enabling digital identification systems, and establishing rules that facilitate interoperability and competition among financial service providers. To this end, we suggest targeted countermeasures such as the government should increase investment in human and physical capital development to empower individuals with limited resources to take advantage of financial services and products. Furthermore, foster partnership between private and public sector to promote the development of digital infrastructure and financial services, leverage the strengths of both sectors to ensure equitable access and benefits for all segments of population.

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Author contributions

All authors contribute equally.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX

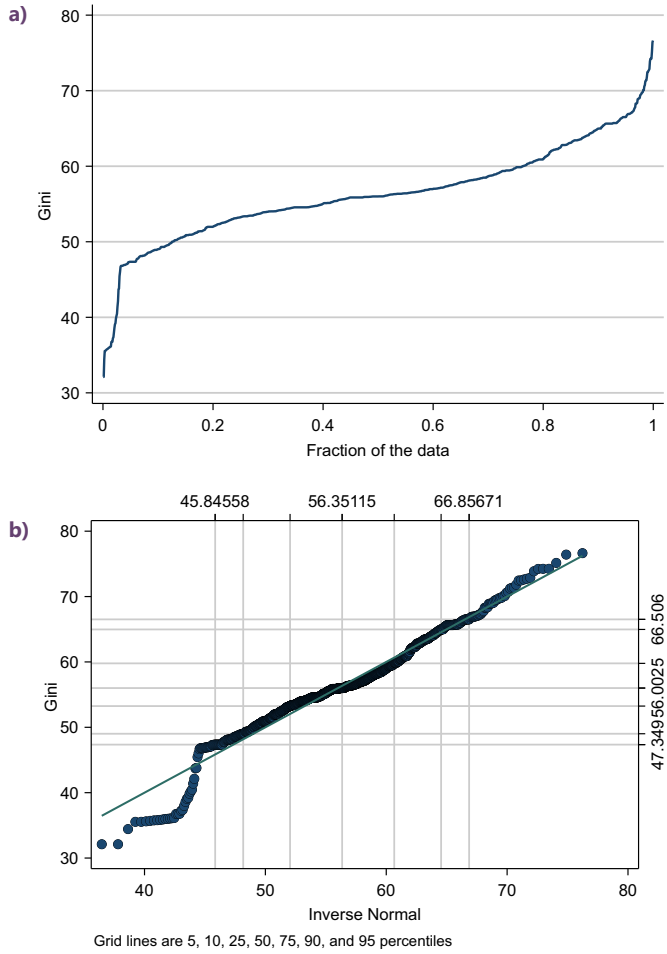

Figure A1. Plots of income inequality (a) quantile and (b)quantile of normal distribution

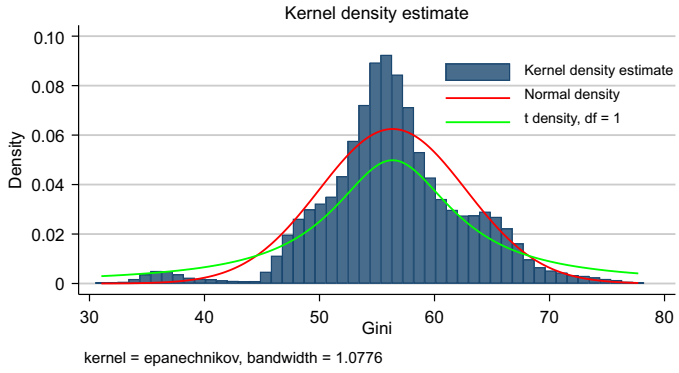

Figure A2. Income inequality kernel density plot

Table A1. IV/GMM estimation with fixed-effects

Variables	Financial market				Financial institutions			
FMA	3.369			0.445				
	(3.324)			(3.299)				
FME		0.0984		–0.457				
		(1.061)		(1.044)				
FMD			13.59***	13.64***				
			(2.376)	(2.416)				
FIA					–1.729			–9.406**
					(3.739)			(3.882)
FIE						–0.830		–0.690
						(1.106)		(1.083)
FID							24.57***	28.39***
							(4.588)	(4.850)
fts	0.469***	0.482***	0.364***	0.362***	0.474***	0.480***	0.478***	0.431***
	(0.0837)	(0.0827)	(0.0836)	(0.0842)	(0.0845)	(0.0827)	(0.0812)	(0.0831)
mbs	–0.0214***	–0.0217***	–0.0229***	–0.0227***	–0.0207***	–0.0212***	–0.0314***	–0.0273***
	(0.00413)	(0.00414)	(0.00405)	(0.00407)	(0.00464)	(0.00418)	(0.00445)	(0.00475)
internet	–0.0465***	–0.0446***	–0.0583***	–0.0589***	–0.0424***	–0.0455***	–0.0501***	–0.0397***
	(0.0132)	(0.0131)	(0.0130)	(0.0131)	(0.0139)	(0.0131)	(0.0129)	(0.0136)
gdp	0.00435	0.00421	0.00128	0.00137	0.00356	0.00520	0.0106	0.00876
	(0.0215)	(0.0215)	(0.0210)	(0.0210)	(0.0215)	(0.0215)	(0.0211)	(0.0211)
gce	0.0551*	0.0542*	0.0179	0.0191	0.0551*	0.0555*	0.0300	0.0299
	(0.0302)	(0.0303)	(0.0303)	(0.0304)	(0.0302)	(0.0302)	(0.0300)	(0.0299)
infla	–0.000458	–0.000515	–0.00103	–0.000998	–0.000606	–0.000564	–5.54e-05	–0.000559
	(0.00366)	(0.00366)	(0.00359)	(0.00359)	(0.00367)	(0.00366)	(0.00360)	(0.00359)
trade	–0.0181***	–0.0184***	–0.0160***	–0.0157***	–0.0187***	–0.0186***	–0.0181***	–0.0200***
	(0.00619)	(0.00621)	(0.00608)	(0.00611)	(0.00623)	(0.00619)	(0.00608)	(0.00610)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01.

Table A2. IV/GMM with a fixed effect for demand-side indicators

Variables	Financial outreach					Financial usage			
atm_1000	–0.0660***				–0.0932***				
	(0.0106)				(0.0133)				
atm_100000		–0.104***			–0.0631***				
		(0.0187)			(0.0182)				
bank_1000			0.0465		0.235***				
			(0.0294)		(0.0461)				
bank_100000				0.212***	–0.178**				
				(0.0618)	(0.0900)				
deposit						–0.00114			0.00597***
						(0.000988)			(0.00116)
depositor							–0.00461***		–0.00810***
							(0.000686)		(0.000899)

End of Table A2

Variables	Financial outreach					Financial usage			
credit								–0.0256	–0.133***
								(0.0264)	(0.0328)
fts	0.759***	0.645***	0.876***	0.881***	0.784***	0.851***	0.658***	0.783***	0.452***
	(0.0854)	(0.0941)	(0.0927)	(0.0873)	(0.0906)	(0.0957)	(0.108)	(0.0885)	(0.110)
mbs	–0.0124**	–0.0102*	–0.0158***	–0.0192***	–0.0104**	–0.0140**	–0.00793	–0.0105**	–0.00244
	(0.00504)	(0.00529)	(0.00485)	(0.00486)	(0.00516)	(0.00681)	(0.00545)	(0.00486)	(0.00619)
internet	–0.0343***	–0.0287**	–0.0557***	–0.0571***	–0.0127	–0.0413***	–0.0256**	–0.0551***	–0.0303**
	(0.0113)	(0.0118)	(0.0115)	(0.0113)	(0.0111)	(0.0141)	(0.0121)	(0.0109)	(0.0130)
gdp	0.0205	0.0259	0.0411**	0.0382*	0.0157	0.0413*	0.0206	0.0480**	0.00306
	(0.0195)	(0.0197)	(0.0201)	(0.0198)	(0.0181)	(0.0240)	(0.0218)	(0.0195)	(0.0219)
gce	0.0924***	0.145***	0.168***	0.164***	0.110***	0.155***	0.0949***	0.165***	0.114***
	(0.0306)	(0.0292)	(0.0305)	(0.0294)	(0.0288)	(0.0323)	(0.0323)	(0.0294)	(0.0332)
infla	0.0498**	0.0610***	0.0520**	0.0520**	0.0630***	0.0531**	0.0396*	0.0527**	0.0468**
	(0.0219)	(0.0223)	(0.0219)	(0.0216)	(0.0204)	(0.0256)	(0.0216)	(0.0211)	(0.0214)
trade	–0.0371***	–0.0460***	–0.0452***	–0.0471***	–0.0467***	–0.0363***	–0.0405***	–0.0436***	–0.0400***
	(0.00819)	(0.00830)	(0.00827)	(0.00813)	(0.00776)	(0.0103)	(0.00828)	(0.00799)	(0.00890)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01.

Table A3. Robustness check-Palma and composite index of financial inclusions

Variables	Financial inclusion			Financial usage			Financial outreach		
	25	50	75	25	50	75	25	50	75
FII	0.221**	0.682**	–0.0523						
	(0.109)	(0.294)	(0.112)						
FU				0.652***	0.621***	0.434***			
				(0.0665)	(0.150)	(0.0511)			
FO							–0.164	–0.600***	–0.764***
							(0.128)	(0.0990)	(0.125)
fts	–0.0630***	–0.175***	–0.0687***	–0.148***	–0.135***	–0.124***	0.00247	0.0779**	0.110***
	(0.0167)	(0.0421)	(0.0214)	(0.0123)	(0.0482)	(0.00972)	(0.0282)	(0.0315)	(0.0272)
mbs	–0.0131***	–0.0112	–0.000258	–0.0149***	–0.00700**	0.000197	–0.0122***	0.00352	0.00316
	(0.00106)	(0.0124)	(0.00179)	(0.00160)	(0.00351)	(0.000967)	(0.000902)	(0.00357)	(0.00232)
internet	–0.00469**	–0.0107	–0.0191***	–0.00573*	–0.0411***	–0.0491***	–0.00481**	–0.0282***	–0.0226***
	(0.00209)	(0.0314)	(0.00631)	(0.00336)	(0.00754)	(0.00276)	(0.00221)	(0.00978)	(0.00659)
gdp	0.0192	0.253	0.0753	0.00116	–0.0104	–0.00961	–0.00621	–0.0472	0.0132
	(0.0186)	(0.267)	(0.0523)	(0.0102)	(0.0500)	(0.0104)	(0.0374)	(0.0850)	(0.0381)
gce	0.0436***	0.0674**	0.154***	0.0386***	0.109**	0.111***	0.0527***	0.0798***	0.0941***
	(0.00827)	(0.0300)	(0.0160)	(0.0121)	(0.0486)	(0.0108)	(0.0200)	(0.0221)	(0.0282)
infla	–0.0191	–0.0999	–0.0146	–0.0471***	–0.0578	–0.0233*	–0.0314**	–0.0454	–0.0354
	(0.0225)	(0.117)	(0.0216)	(0.00547)	(0.0757)	(0.0139)	(0.0152)	(0.0530)	(0.0418)
trade	–0.00433	0.0175	–0.00801*	0.00362*	–0.00434	–0.00358***	–0.00216	0.00455	0.00202
	(0.00268)	(0.0130)	(0.00420)	(0.00214)	(0.0198)	(0.000869)	(0.00641)	(0.00433)	(0.00653)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.01.

Table A4. Structural quantile function -instrumental variables results

Variables	Quantiles								
	25	50	75	25	50	75	25	50	75
Panel A:									
FM	7.984	15.32***	22.20*						
	(18.21)	(5.178)	(11.34)						
FI				24.49***	24.03***	23.47***			
				(3.804)	(3.053)	(2.919)			
FD							21.02***	24.75***	28.94***
							(6.207)	(4.456)	(3.464)
fts	–0.300	–0.294	–0.289	–0.500***	–0.465***	–0.422***	–0.438***	–0.448***	–0.459***
	(0.242)	(0.329)	(0.847)	(0.0611)	(0.0613)	(0.0896)	(0.0696)	(0.0660)	(0.0834)
mbs	–0.0326***	–0.0278	–0.0233	–0.0353***	–0.0290***	–0.0214**	–0.0343***	–0.0314***	–0.0281***
	(0.00983)	(0.0372)	(0.0680)	(0.00967)	(0.00860)	(0.00963)	(0.00921)	(0.00847)	(0.00979)
internet	–0.0780	–0.0567	–0.0368	–0.121***	–0.107***	–0.0905***	–0.0991***	–0.0809***	–0.0605*
	(0.0506)	(0.112)	(0.176)	(0.0308)	(0.0276)	(0.0312)	(0.0303)	(0.0282)	(0.0339)
Panel B:									
FO	–2.465***	–2.101***	–1.685*						
	(0.454)	(0.618)	(0.912)						
FU				1.050	1.158**	1.276***			
				(0.648)	(0.483)	(0.468)			
FII							–0.387	0.266	1.064
							(0.631)	(0.709)	(0.945)
fts	0.334***	0.243*	0.139	–0.304***	–0.344***	–0.387***	–0.108	–0.211**	–0.337**
	(0.0884)	(0.130)	(0.198)	(0.111)	(0.0854)	(0.0815)	(0.0868)	(0.104)	(0.143)
mbs	–0.0226**	–0.00674	0.0114	–0.0352***	–0.0231**	–0.00986	–0.0298***	–0.0175	–0.00240
	(0.0108)	(0.0107)	(0.0147)	(0.0117)	(0.0114)	(0.0147)	(0.0112)	(0.0112)	(0.0152)
internet	–0.0588**	–0.0760**	–0.0957**	–0.106***	–0.118***	–0.131***	–0.0821***	–0.102***	–0.126***
	(0.0267)	(0.0298)	(0.0416)	(0.0337)	(0.0304)	(0.0383)	(0.0270)	(0.0290)	(0.0418)
gdp	0.0117	0.0226	0.0350	0.0238	0.0201	0.0160	0.0167	0.0151	0.0132
	(0.0391)	(0.0407)	(0.0529)	(0.0477)	(0.0466)	(0.0561)	(0.0427)	(0.0438)	(0.0562)
gce	0.205***	0.273***	0.350***	0.205***	0.271***	0.343***	0.221***	0.282***	0.356***
	(0.0404)	(0.0384)	(0.0588)	(0.0670)	(0.0462)	(0.0523)	(0.0500)	(0.0404)	(0.0536)
infla	–0.118***	–0.0802*	–0.0370	–0.150***	–0.119***	–0.0846	–0.140***	–0.113**	–0.0805
	(0.0457)	(0.0466)	(0.0636)	(0.0482)	(0.0458)	(0.0586)	(0.0460)	(0.0457)	(0.0605)
trade	0.00798	–0.0106	–0.0319***	–0.0126	–0.0212*	–0.0304***	–0.00446	–0.0183*	–0.0352***
	(0.0120)	(0.00886)	(0.00937)	(0.0144)	(0.0110)	(0.0104)	(0.0139)	(0.0103)	(0.00994)

Note: Standard errors presented in parentheses: *, **, *** denoted significance at 0.1, 0.05, 0.