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Does digital financial innovation enhance financial deepening and growth in Kenya?

Roseline Misati
Central Bank of Kenya, Nairobi, Kenya
Jared Osoro
FSD Africa, Nairobi, Kenya
Maureen Odongo
Central Bank of Kenya, Nairobi, Kenya, and
Farida Abdul
Strathmore University, Nairobi, Kenya

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Abstract

Purpose – The purpose of this paper is to examine the effect of digital financial innovation on financial depth and economic growth in Kenya.

Design/methodology/approach – The study utilized autoregressive distributed lag (ARDL) model, which is preferable over other time series methods as the model allows application of co-integration tests to time series with different integration orders and is flexible to the sample size including small and finite.

Findings – The main findings of this paper are as follows: first, there is evidence of a positive relationship between digital financial innovation and financial depth with the strongest impact emanating from Internet usage and mobile financial services and the lowest impact from bank branches; second, the results reveal a significant positive impact of financial depth on economic growth consistent with the supply-leading finance theory.

Practical implications – The results of the study imply a need for investment in technology-enabling infrastructure for digital financial services (DFS) and a redesign of strategies to avoid further financial exclusion of low-income earners due to the unaffordability of digital devices and financial and digital illiteracy.

Originality/value – The study is original and important for policymakers as the study provides insights on the components of financial innovation that are growth-enhancing in Kenya, considering that some aspects of innovation can be growth-retarding as was demonstrated during the global financial crisis.

Keywords Digital financial innovation, Financial depth, Growth

Paper type Research paper

Financial innovation is a double-edged sword; it can be a force for good, but it can also have negative consequences since financial innovations are often associated with financial crises and financial malpractice, in which case the use of innovation is predatory rather than the innovation itself (Diaz-Rainey and Ibikunle, 2012).

1. Introduction

Financial innovation has become an integral part of financial deepening in Kenya. The rapid transformation of the financial system has been facilitated by vibrant technological innovations that have led to the proliferation of new financial products, multiple delivery channels, adoption of new business models and development of digital financial services (DFS) [1]. Usage of DFS has not only increased efficiency in financial service delivery, but has also enhanced speed, transparency, security and availability of tailored financial services that serve all categories of consumers (Pazarbasioglu *et al.*, 2020). Notable examples of technologically enabled financial innovation in Kenya include branchless banking,

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electronic payment systems, Internet banking and mobile banking. The innovations have also redefined the delivery of services as financial institutions strive to enhance access to customers as well as differentiate their products and services (financial sector deepening, (FSD), 2015, 2019). Banks in Kenya have thus continuously leveraged on digital financial platforms to manage micro-accounts, build up deposits and extend financial services to the previously unbanked and underserved population (Ndung'u, 2019, 2018). For instance, banks have introduced new products that are pegged on digital payments.

A key development in the digital bank and mobile money technology was the adoption of "Fuliza," a digital overdraft facility offered by banks through Safaricom mobile money operator (FinAccess, 2021). The overdraft facility enables Safaricom customers, mostly at the retail end, to make payments, receive money, pay bills and buy goods and services from their phones. The fact that transfers are possible even for values as low as a tenth of a dollar and loans accessible on digital platforms for values as low as one dollar has made it possible for consumers of all segments, including previously excluded low-income earners, to enjoy diversified financial services. Formal non-bank products have also ventured into the credit market through mobile money lending apps.

The outlined progress notwithstanding, the implications of these new developments in the financial system are not well understood or structurally documented, yet pertinent questions on financial innovation-growth nexus remain unanswered. Moreover, the existing literature reveals no consensus on the finance–growth nexus (Levine, 1997; Gregorio and Guidotti, 1995). The literature on finance–growth nexus is dominated by four schools of thought. One strand of the literature argues that financial innovation expands economic activities through various channels such as financial inclusion, international trade, remittances channel and financial efficiency (Qamruzzaman and Jianguo, 2017; Zandi *et al.*, 2016; Laeven *et al.*, 2015; Hao and Hunter, 1997). The other points to possibilities of instabilities arising from financial innovation, in which case excessive or inappropriate usage of some components of financial innovation without proper regulations can lead to financial instability (Camelia and Angela, 2011; Boot and Marinc, 2010). The third strand contends that financial development is only beneficial to economic growth up to a certain threshold, beyond which the effect turns negative (Arcand *et al.*, 2015). The fourth strand explores stages of development hypothesis where supply-leading and demand-following theories are considered. The proponents of this hypothesis contest the causality of finance and growth (Tariq *et al.*, 2020; Honohan, 1966).

While the Kenyan experience of financial innovation has been globally acknowledged, little empirical research is documented on this subject, especially on how it relates with financial depth and growth. Few attempts on the subject have mainly focused on the linkages between financial innovation and bank performance, implications of financial innovation on monetary policy transmission as well as an examination of financial innovation-growth linkage directly without considering financial depth as the main channel through which financial innovation impacts economic growth (Chipeta and Muthinja, 2018; Cherotich *et al.*, 2015; Ndirangu and Nyamongo, 2015; Muiruri and Ngari, 2014; Mwinzi, 2014). These studies have several shortcomings. First, they ignore the possible direct link between financial innovation and financial deepening, yet several studies show that financial innovation affects growth through many channels, financial deepening being the most important. Second, they ignore the separate effects of different components of financial innovation. Third, they assume the direction of causality from financial innovation to economic growth, yet there is evidence of reverse causality between financial innovation and financial depth as well as financial depth and economic growth. Fourth, they have not accounted for recent policy changes, notably the introduction of interest rate controls in 2016 and its subsequent removal in 2019. Against this background, this study seeks to answer the questions as follows:

(1) Why are countries having different outcomes of financial innovation on growth and what does this imply for Kenya?

(2) Which components of financial innovation are growth-enhancing and which ones are growth-retarding in Kenya?

(3) Is causality between financial innovation and economic growth an issue in Kenya?

(4) What are the effects of interest rate controls on financial depth and growth?

To address the foregoing questions, the study seeks to empirically establish the linkage between financial innovation and financial depth and the effects of financial depth on economic growth. In this regard, the study contributes to the literature in at least four ways as follows:

(1) It analyses the impact of different components of financial innovation on financial depth and economic growth;

(2) It examines whether any reverse causality exists between financial innovation and financial depth, and then links that to economic growth;

(3) It utilizes the autoregressive distributed lag (ARDL) approach that has not been utilized in previous studies using Kenyan data and

(4) It accounts for rapid policy changes in the financial landscape in the recent past by controlling for interest rate caps.

The study utilizes ARDL method that is most suited for time series data where variables are integrated of different orders and the sample size is small. The ARDL approach has better statistical properties relative to other time series tests such as Engle–Granger co-integration test because it uses unconstrained error correction models (ECMs) and captures dynamic effects of both the dependent and independent variables (Nkoro and Uko, 2016).

Our findings largely support growth-enhancing effects of financial innovation but through the financial deepening channel. The study reveals a long-run positive relationship between digital financial innovation and financial depth with the strongest impact emanating from Internet usage and mobile financial services and the lowest impact from bank branches. It further shows that financial depth is positive and significant in explaining economic growth consistent with the finance-growth theories, but the impact of financial innovation on growth is indirect through the financial depth channel. The results show a weak relationship between Gross Domestic Product (GDP) and financial depth, thus implying that the supply-leading theory dominates over the demand-pulling hypothesis of the finance-growth theory. The findings also confirm that restrictions on prices, particularly on interest rate, are not conducive for loan growth and financial depth. The Granger causality tests largely show unidirectional relationship from financial innovation indicators to financial depth regardless of the financial indicator used and from financial depth and innovation to economic growth.

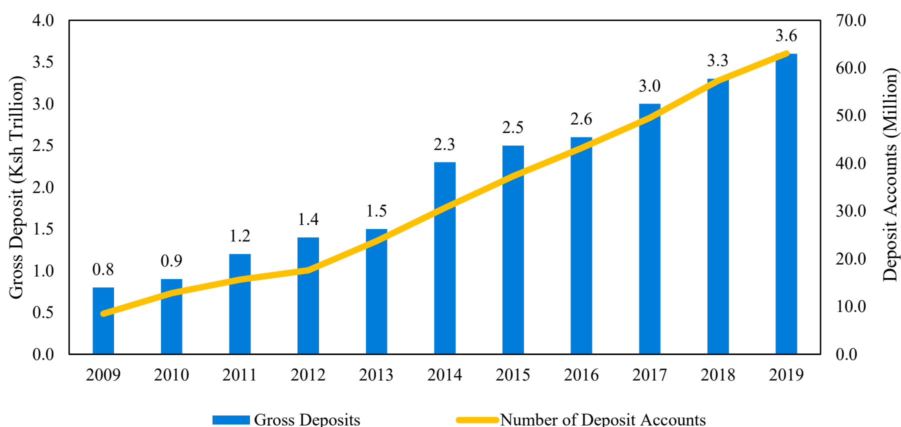
Besides financial innovation, the results show that remittance flows and trade openness are important in explaining financial depth. However, whereas the effect of remittances on financial depth is positive in the long-run, it has a negative effect in the short run partly because remittance inflows in the short run would be devoted to consumption rather than investment. However, the results indicate a positive relationship between remittances and economic growth both in the short run and in the long run, implying that remittances not only affect economic growth through the financial deepening channel but also through other channels. The study also shows that government expenditure and inflation have negative effects on growth, while public debt has a positive effect suggesting a complementary role of debt on economic growth.

The rest of the paper is organized as follows. Section 2 presents an assessment of financial innovation, the uptake of financial services and products and the infrastructure supporting digital platforms in Kenya. Section 3 highlights theoretical and empirical literature on financial innovation and the finance–growth nexus. Section 4 presents the data and research methodology. Section 5 provides the empirical findings and discusses the results while Section 6 concludes with policy implications. Tables A1–A3 provide supplementary information on Granger causality and unit root tests.

2. Dynamics of financial innovation indicators and enabling infrastructure in Kenya

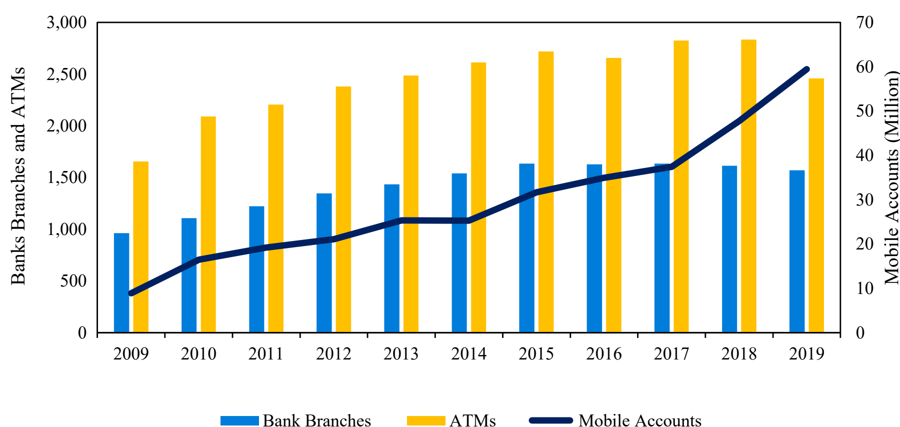
In this section, we analyze the evolution of financial innovation indicators and the enabling infrastructure in form of access to electricity, mobile network coverage and Internet connectivity. These are prerequisites for adoption and usage of nearly all the new financial products and services. Financial innovation in the Kenyan banking industry has been associated with convenience, effectiveness and efficiency. These attributes are deemed to have enhanced the economy's financial depth as revealed by the increased number of deposit accounts from 8.5 million in 2009 to 62.01 million in 2019, accompanied by an increase in gross deposits from Kenya shillings (Kshs) 0.8 trillion to 3.6 trillion (Figure 1). As pointed out by Ndung'u (2018), the growth in deposit accounts depicts increase in access to financial services. In addition, Figure 2 shows that digital banking has become a gateway to financial services, and it has reduced the number of physical brick and mortar branch networks and automated teller machine (ATM) usage. Besides the savings associated with operational and maintenance costs, these developments translate into travel time savings and enhanced customer convenience and safety.

Before digitization, direct transaction costs, such as account opening fees and minimum account balance requirements, and indirect costs, such as travel time and the opportunity costs of visiting bank branches, were significant barriers to financial inclusion (FSD, 2019). Over-the-counter withdrawals were the most expensive, with no variations on the costs even for small transactions. However, withdrawal transactions over digital channels were relatively lower (Figure 3).



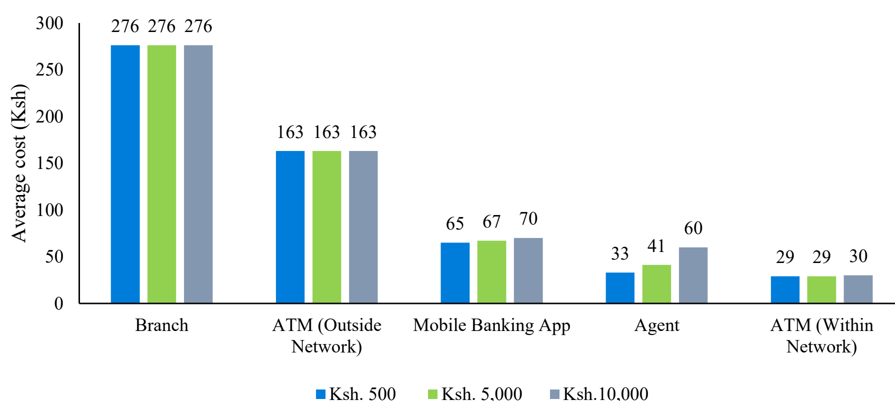
Source(s): Central Bank of Kenya

Figure 1.
The value and number of deposit accounts in Kenya



Source(s): Central Bank of Kenya

Figure 2. Number of bank branches, ATMs and mobile accounts in Kenya



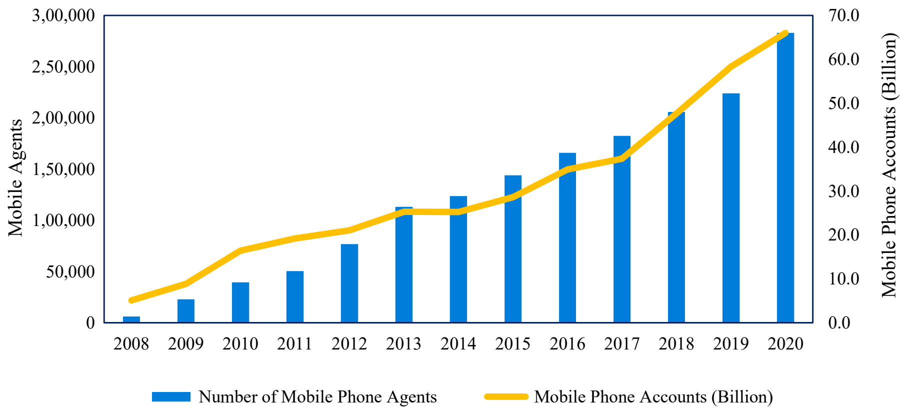
Source(s): Financial Sector Deepening, 2019

Figure 3. Average withdrawal cost by channel and transaction amount

Mobile money transfer services have continued to gain popularity since their introduction in 2007. Based on end period data, the number of mobile phone agents and mobile phone accounts grew from 6,104 to 5.1 million, respectively, in 2008 to 282,929 and 66.0 million in 2020 (Figure 4). The volume and value of mobile phone money transfers also increased from 10.2 million transactions worth Kshs 27bn in 2008 to 181.3 million transactions worth of Kshs 605.7bn in 2020 (Figure 5).

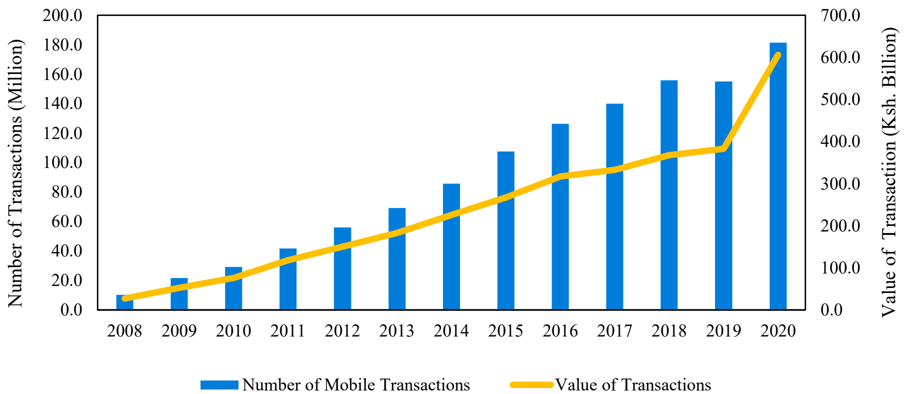
Kenya's mobile phone financial services have integrated with the banking sector to form a robust digital mobile banking ecosystem and have yielded varied value-added products and services. The digital mobile phone platform uses credit rating measures by FinTechs to provide unsecured loans through mobile platforms. This has provided retailers and the micro and small-scale enterprises opportunity for online credit facility and enlarged outreach, in essence enabling e-commerce intertwined through linkages between both financial and non-financial institutions.

Comparison between pre-COVID, March–December 2019 and post-COVID, March–December 2020, indicates a shift in the channel used for transaction (Figure 6).



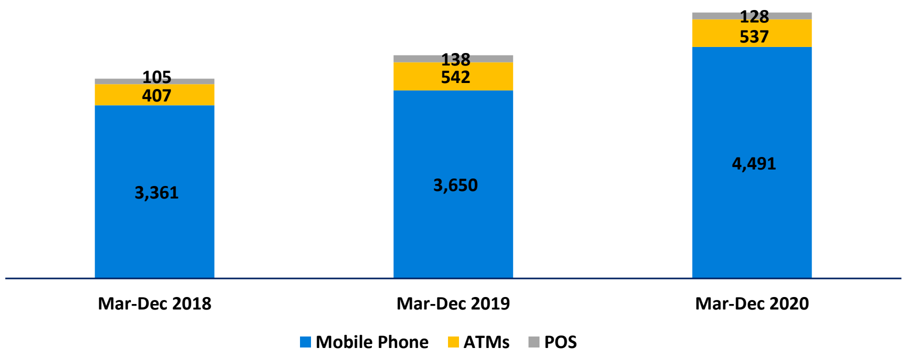
Source(s): Central Bank of Kenya database

Figure 4.
Number of mobile phone agents and accounts



Source(s): Central Bank of Kenya database

Figure 5.
Value and number of mobile phone transactions



Source(s): Central Bank of Kenya database

Figure 6.
Value of digital transactions, pre- and post-COVID-19 pandemic (Kshs billion)

Post-COVID pandemic value of transactions through physical channels (ATM machines and points of sale) declined while they increased through digital channels (mobile phone).

Investment in digital infrastructure such as Global System for Mobile Communication (GSM) network coverage, mobile and Internet platforms, smartphones and mobile apps have enabled the rapid uptake of DFS in developed economies. However, mobile network coverage in Kenya is still dependent on the slower narrowband second generation-2G GSM technology with penetration rate of 50.6% in 2019 compared to the faster broadband fifth generation-5G technology that is currently used in most of the developed economies. Kenya's uptake of third generation-3G and fourth generation-4G technology remains low, at 38.0% and 8.7%, respectively, in 2019 (GSMA, 2020). Because of the narrowband network coverage, the quality and reliability of Internet remains an issue especially when using 2G. This calls for continued investment in mobile networks coverage to allow for expansion on 4G network coverage and faster move to 5G technology in line with growing demand for mobile data services and the desire for improved service quality.

Even with the observed shift toward cashless transactions in Kenya, three notable constraints are binding. First, the cost of smartphones and internet-enabled devices are a key barrier to mobile ownership and mobile Internet adoption. According to GSMA (2019), the cost of an entry-level internet-enabled device is more than 20% of average monthly income in low and middle-income countries (LMICs).

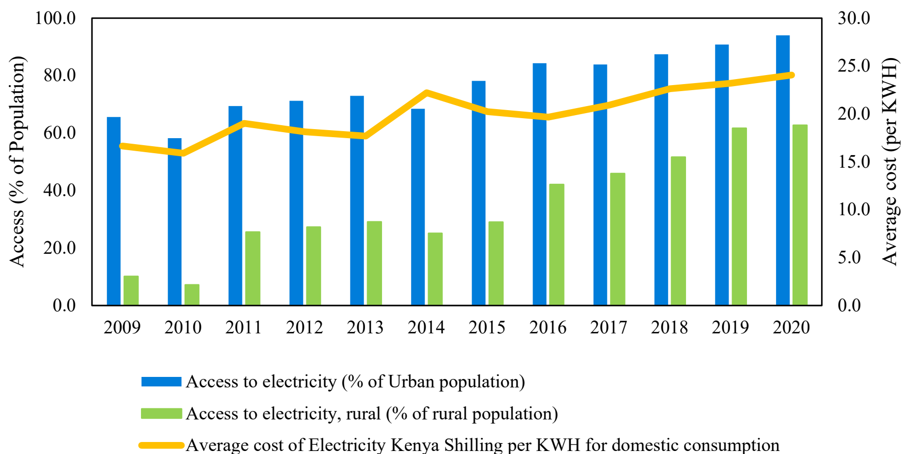
Further, these devices highly depend on the availability of broadband network coverage, which remains limited in Kenya.

Second, the high cost of mobile data remains a barrier to connectivity in Kenya manifested in relatively low mobile Internet penetration at 27% in 2019, compared to South Africa (31.3), Nigeria (47%) and Cote d Ivoire (28%). Even then, the poorest 20% of the population in Kenya spend approximately 8.0% of their monthly income on the low consumption basket of 500 MegaByte (MB) mobile data and 26.5% of their monthly income on the medium consumption basket of 1 GigaByte (GB) of data +250 min of voice +100 Short Message Service (SMS) mobile data. This is above the United Nations target of 2% of monthly income for the 1 GB of mobile data of their average monthly earnings on data.

Third is the cost of electricity. Most of the digital innovations rely on not only Internet connectivity, but also on access to affordable and reliable electricity supply. Power grids in Kenya have become much more widespread both in rural and urban areas. Despite the increase in the supply of electricity, the cost remains prohibitive to the poor population. The household electricity price for Kenya was Ksh 24.78 per Kilowatt hour (Kwh) in September 2021, having increased gradually over the years (Figure 7). This is relatively expensive compared to Ethiopia (Ksh 0.82 per Kwh), Ghana (Ksh. 5.49 per Kwh), Tanzania (Ksh 11.57 per Kwh), South Africa (19.29 per Kwh) and Uganda (Ksh 21.04 per Kwh). With the high cost of electricity, users end up spending a high proportion of their revenue by simply charging their mobile phone and/or accessing Internet. The lack of affordable electricity supply therefore represents a barrier to mobile phone usage and Internet connectivity for off-grid subscribers, even under the GSM broadband network coverage.

3. Literature review

Earlier theoretical literature on the finance–growth nexus focused on historical experiences of England and the United States of America to illustrate the role of the financial system in various channels of economic growth (Bagehot, 1873; Hicks, 1969; Schumpeter, 1912; Robinson, 1952). Recent theories have based the growth–finance nexus on four main schools of thought with some authors highlighting positive outcomes (Frame *et al.*, 2018; Tahir *et al.*, 2018; Beck *et al.*, 2016; Boot and Marinc, 2010; Henderson and Pearson, 2011; Blach, 2011) and others pointing to complexities associated with financial innovation particularly since the



Source(s): World Bank Database and Stimatracker, Kenya

Figure 7.
Access to electricity in Kenya

global financial crisis (Khraisha and Arthur, 2018; Beck *et al.*, 2016; Allen, 2012; Henderson and Pearson, 2011). The other two theories are mainly focused on optimum levels of financial development on growth and causality between finance and growth (Tariq *et al.*, 2020; Arcand *et al.*, 2015).

Growth-enhancing financial innovation theories contend that innovation helps to correct market inefficiencies and imperfections, thus assisting economic agents to obtain desired outcomes, besides minimizing economic volatility (Henderson and Pearson, 2011). It, therefore, raises the efficiency of financial intermediation by increasing the variety and quality of financial products and services, including provision of new choices of financial products, services, markets and players to households, consumers and investors. This results in improved matching of the needs of individual savers with those of firms raising funds. Furthermore, financial innovation helps reduce agency costs, facilitate risk sharing, complete the market, reduce transaction costs and ultimately improve allocative efficiency and economic growth (Beck *et al.*, 2016; Boot and Marinc, 2010). Developments in the payment systems in the form of digital payment expedite the exchange of goods and services and expand the menu of savings and lending products, leading to high growth outcomes (Frame *et al.*, 2018; Tahir *et al.*, 2018; Blach, 2011).

The innovation-fragility view popularized after the global financial crisis posits that financial innovation that reduces asymmetric information increases risk-taking due to agency problems between bank owners and managers or because of lower costs of fragility (Beck *et al.*, 2016). Under this line of thought, it is argued that financial innovation introduces complexity to exploit uninformed investors where structured equity products are significantly overpriced to extract money from investors who do not fully understand the alternatives to what they are buying (Ammann *et al.*, 2017; Allen, 2012; Henderson and Pearson, 2011). In this case, it is assumed that issuers may have incentives to disguise the nature of products to exploit customers or to increase complexity making it harder for buyers to make rational choices.

Diaz-Rainey and Ibikunle (2012) categorize the dark side of financial innovation into abuse of financial innovation and unintended consequences of financial innovation besides predatory schemes. In the former case, while financial innovation would be correcting some market failure, it may be used inappropriately due to unsuitable incentives, malfeasance and

financial illiteracy of the buyer. In the latter case, financial innovation may be beneficial but only to some segments of the economy, but it is generally detrimental as was demonstrated by the case of credit derivatives that hedged risk at firm level but augmented financial contagion at the aggregate level.

Another strand of literature uses economic theory entailing demand and supply models. The idea here is to decide whether a financial innovation occurs due to market demand for new financial innovations or financial innovation is something that emerges independent of market factors. Demand for financial innovations can originate from the client side in the form of household need to borrow and invest money or firm demand for innovative ways to hedge risks and reduce taxes. Demand may also originate from the innovator's side, for example, financial firms facing external or internal constraints. Proponents of the supply-side theory of financial innovation argue that regulators and conventional economic theory do not consider the incentives of the financial system to supply financial innovations, mainly financial instruments. In this case, the main incentive of financial intermediaries to innovate is to recreate the monopolistic condition that is usually lost due to the non-patentability of financial innovations. The financial intermediaries accomplish this by either accelerating the rate of financial innovation or increasing the complexity of financial products or services (Khraisha and Arthur, 2018).

Related economic theories are based on the arguments that financial innovation expands economic activities through promoting financial inclusion, facilitating financial transactions in international trade, enabling remittances and uplifting financial efficiency eventually playing a fundamental role in economic growth. Innovation in the financial system has led to developments such as mobile, Internet banking services, new financial institutions and instruments, product diversity, efficient financial intermediation, introduction of new channels for efficient resource allocation, creation of new corporate structures and credit facilities, resulting in efficiency gains that feed into improved economic growth. Financial innovations lead to a higher level of savings and capital accumulation and, consequently, a higher level of economic growth (Nazir *et al.*, 2020; Mollaahmetoglu and Akcali, 2019; Qamruzzaman and Jianguo, 2017).

Some studies focused on financial depth–growth nexus argue that financial development is only beneficial to economic growth up to a certain threshold, beyond which the effect turns negative (Arcand *et al.*, 2015). These studies argue that although financial development boosts a country's resilience and growth, there are tradeoffs between growth and stability underpinned by instances of "too much finance", in which case the costs outweigh the benefits of financial development. The studies, however, conclude that most emerging markets are still in a favorable region where further financial development promotes both higher growth and stability (Sahay *et al.*, 2015).

Recent empirical studies in African countries that are based on earlier theories developed for advanced economies reveal no consensus in the finance–growth nexus (Muazu and Alagidede, 2018; Assefa and Mollick, 2017). Studies entrenched on the arguments that financial innovation expands economic activities through various channels find positive linkages between financial innovation and economic growth (Ozurumba and Onyeiwu, 2019). Other studies show that growth outcome of financial innovation is sensitive to the indicator used emphasizing the fact that different components of financial innovation serve different purposes in the financial system and growth process (Bara and Mudzingiri, 2016; Ajide, 2016).

4. Data, variables and methodology

4.1 Data sources

This study uses quarterly data covering the period 2005–2020. Variable description, abbreviations and data sources are provided in Table 1 below.

Table 1.
Variable definition and data sources

Variable (Abbreviation)	Description	Source
RGDP	Real gross domestic product	Kenya National Bureau of Statistics (KNBS)
Topen	Trade openness defined as total exports and imports divided by GDP	Trade data from Kenya Revenue Authority
Cred	Credit to the private sector as a share of GDP	Central Bank of Kenya (CBK)
ER	Nominal exchange rate expressed as Kenya shilling per USA dollar	CBK
CPI	Consumer price index	KNBS
Rem	Total remittance inflows	CBK
Lend	Weighted commercial banks' lending interest rate	CBK
MobV	Value of mobile transactions as a share of GDP	CBK
MobAcc	Number of mobile accounts	CBK
MobAgent	Number of mobile agents	CBK
Branch	Number of bank branches	CBK
ATMV	Value of ATM transactions	CBK
BankAcc	Number of bank accounts	CBK
GovCons	Government expenditure as a share of GDP	KNBS
GFCF	Gross fixed capital formation as a share of GDP	KNBS
Pubdebt	Public debt as a share of GDP	KNBS
Internet	Number of individuals using Internet as a percentage of total population	World Development Indicators, World Bank

4.2 Model and a priori expectations

The initial model that links financial innovation to financial depth is specified as follows:

$$FIND_t = \delta_0 + \gamma_1 \mathrm{Finn}_t + \gamma_2 \mathrm{X}_t + \varepsilon_t, \ldots, \quad (1)$$

where FIND represents financial depth variable (credit to the private sector as a share of GDP), *Finn* represents financial innovation indicators used to capture innovative financial services (value of mobile transactions, number of mobile accounts, number of mobile agents, value of ATM transactions and individuals using Internet) and traditional financial access indicators (number of bank branches and accounts) while X represents control variables in the regression models. Consistent with previous studies, besides financial innovation and access variables, other control variables include, trade openness, remittances, inflation, real GDP, exchange rate and lending interest rate and t represents the time dimension of the data. The indicators of financial innovation are based on the measures that have been used in previous studies, (Nguena, 2019; Afi, 2019; Bara and Mudzingiri, 2016; Ekpu, 2015; Muiruri and Ngari, 2014).

We reformulate equation (1) into a long-term relationship as represented in equation (2), where Z is the predicted residuals from the regression of equation (1).

$$\mathrm{Z} = LFIND_t - \delta_0 - \gamma_1 LFinn_t - \gamma_2 \mathrm{LX}_t, \ldots, \quad (2)$$

Following previous work, we express equation (2) in ARDL form as represented in equation (3) below (Ofori *et al.*, 2019; Jalil and Ying, 2008; Pesaran *et al.*, 2001).

$$\Delta \mathrm{LFIND}_t = \delta_0 + \beta_1 \mathrm{LFinD}_{t-1} + \beta_2 \mathrm{LFinn}_{t-1} + \beta_n \mathrm{LX}_{t-1} + \sum_{i=1}^{p} \rho_i \Delta \mathrm{LFinD}_{t-i} + \sum_{i=1}^{q} \delta_i \Delta \mathrm{LFinn}_{t-i} + \sum_{i=1}^{r} \tau_n \Delta \mathrm{LX}_{t-\mathrm{i}} + \varepsilon_t, \ldots, \quad (3)$$

where LFIND represents the log of financial depth indicator, LFinn is the log of financial innovation indicators and LX represents the log of the control variables in the model. In addition,

p, q and r are optimal lag lengths;

ρi, δi and τi are the ARDL model's short-term dynamics;

$\beta 1$, $\beta 2$, . . ., and βn are long-run multipliers;

Δ is the first difference operator;

δ_0, is a constant term and

ε_t is the white noise error term.

A compact ECM is specified in equation (4) below.

$$\Delta \mathrm{LFIND}_t = \delta_0 + \sum_{i=1}^{p} \rho_i \Delta \mathrm{LFIND}_{t-i} + \sum_{i=1}^{q} \delta_i \Delta \mathrm{LFinn}_{t-i} + \sum_{i=1}^{r} \tau_i \Delta \mathrm{LX}_{t-i} + \alpha ECM_{t-1} + \varepsilon_t, \ldots, \quad (4)$$

where ECM_{t-1} is the error correction term representing the adjustment speed of the dependent and independent variables to their long-run equilibrium following any shock.

Financial innovation enhances the process of mobilization of financial surpluses from savers and enables their channeling to the most productive investment avenues, with positive implications on credit growth and financial intermediation. The outcome of financial innovation also helps in reducing costs and risks as well as improving the menu of services available to the consumers (Mishra, 2008; Frame and White, 2004). In particular, mobile phones reduce banks' costs since they facilitate switching from large, fixed infrastructure cost structure in rural and poorer areas to a per-transaction variable cost structure. It is cost efficient for customers, as it reduces traveling costs to and from distant branches. Besides costs reduction, financial innovation linked to mobile phones comes with the benefits of convenience and a level of control and immediacy to customers that cannot be provided by traditional bank models.

The interaction between financial service providers and their clients through mobile phones creates an opportunity for information capturing, lack of which has previously been one of the barriers to financial depth (Chinoda and Kwenda, 2019). Moreover, as pointed out by Hasan *et al.* (2013) and Berger (2003), usage of digital methods of payments such as Internet banking improves costs and lending capacity. This is because of reduction in costs of "back-office" activities that represent majority of financial institutions operational costs and improved consumer benefits from enhanced "front-office" technology. A priori, we, therefore, expect a positive relationship between financial innovation indicators and financial depth.

Previous studies support a positive relationship between remittances and financial development, in which case remittances through formal channels foster banking outreach and depth since these channels provide opportunities for encouraging savings, increasing deposits and deepening financial inclusion and economic growth. However, other studies show that remittances relax borrowing constraints subsequently decreasing the marginal utility of wealth and increasing the consumption of all normal goods, including leisure. In this case, remittances lead to substitution of income for leisure, adversely impacting accumulation of capital (Eftimoski and Josheski, 2021; Misati *et al.*, 2019; Berrak *et al.*, 2018; Akkoyunlu, 2013; Guha, 2013).

Trade openness contributes to the development of the financial sector by generating a demand for new financial products, including instruments for trade finance and hedging of

risks (Bayar *et al.*, 2017; Siong and Muzafar, 2009; Svaleryd and Vlachos, 2002). Output is included in the financial sector depth equations in line with demand-following theory, which postulate that as the real sector develops, it generates new demand for financial services and induces its growth (Banerjee and Ghosh, 1998; Honohan, 1966).

Inflation and exchange rate capture the macroeconomic environment. Several studies indicate that high inflation erodes savings returns, leading to reduced incentives to save, and hence fewer savers and savings amounts which have negative implications on financial depth and economic growth. The exchange rate affects financial development and growth through the finance channel and trade channel. Appreciation of the exchange rate eases financial conditions and strengthens the balance sheet of domestic borrowers in foreign currency with a positive effect on either total or foreign denominated credit and, ultimately, economic growth. Lending interest rates is included to capture the impact of monetary policy stance, and a negative relationship with the dependent variable is expected (Beckmann and Mariarosaria, 2021; Aluko and Ajayi, 2018; Ayadi *et al.*, 2015; Bittencourt, 2011).

Previous studies show that high public debt acts as a tax on future output, reduces the incentive to save or invest, raises the discount rate of potential investors due to future tax associated with outstanding debt burden and leads to distortions and slowdown in growth. Total government expenditures as a share of GDP controls for the possible complementarity or substitutability of publicly financed capital expenditures and private investment with implications on growth. A priori, an ambiguous sign is expected depending on whether it crowds in or crowds out investment (Kurihara, 2015; Barth and Cordes, 1980).

4.3 Estimation method

This study considers ARDL as the most preferred approach over alternatives such as Engle and Granger two-step procedure and Johansen that lack power when considering finite samples, which are prone to simultaneous equation bias and have no provision for variables integrated of different orders (Johansen, 1991; Johansen and Juselius, 1990; Engle and Granger, 1987) [2]. The ARDL has advantages over the other co-integration methods as follows: (1) it allows for the application of co-integration tests to time series of different integration orders; (2) it is flexible to the sample size which can either be small or finite (consisting of 30–80 observations) in which it gives more reliable results in small samples relative the alternatives; (3) it has better statistical properties relative to Engle–Granger co-integration test because it uses unconstrained ECMs and (4) it captures dynamic effects of both the dependent and independent variables, besides eliminating error serial correlation by including sufficient lags and allowing estimation of short-term and long-term simultaneously (Qamruzzaman and Jianguo, 2018; Nkoro and Uko, 2016; Karamelikli and Bayar, 2015; Adu *et al.*, 2013; Jalil and Ying, 2008; Pesaran *et al.*, 2001).

5. Findings of the study

In this section, we present results for co-integration in Table 2. The results for long-run equations are presented in Tables 3 and 5, while results for short-run models with the error correction term are reported in Tables 4 and 6.

5.1 Co-integration tests

Co-integration tests are conducted based on equation (3), whereby we specify the null hypothesis of no co-integration as H0: $\beta_1 = \beta_2 = \ldots = \beta_n = 0$ against the alternative H1: $\beta_1 = \beta_2 \neq \ldots \beta_n \neq 0$ that co-integration exists. A rejection of the null hypothesis implies that co-integration exists. We test this hypothesis by comparing the F-statistics obtained from Wald's test with the critical values for small samples or between 30 and 80 observations as provided by Narayan (2005).

Model**	F-statistic	Outcome based on Narayan (2005)
Model 1: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *MobV*)	9.31*	Co-integrated at 1%
Model 2: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *MobAcc*)	7.97*	Co-integrated at 1%
Model 3: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *Branch*)	7.56*	Co-integrated at 1%
Model 4: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *BankAcc*)	5.33*	Co-integrated at 5%
Model 5: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *ATMV*)	15.7*	Co-integrated at 1%
Model 6: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *Internet*)	28.01*	Co-integrated at 1%
Model 7: Cred = f(Cred, Rgdp, Topen, Er, CPI, Rem, Lend, *MAgent*)	23.47*	Co-integrated at 1%
Critical values based on Narayan (2005)		
Critical values for Model 1–4	*Lower bound*	*Upper bound*
1%	4.31	5.965
5%	3.121	4.564
Critical values for Model 5–6	*Lower bound*	*Upper bound*
1%	4.799	6.821
Critical values for Model 7	*Lower bound*	*Upper bound*
1%	4.459	6.206

Table 2. Co-integration tests: the dependent variable is credit to the private sector

The co-integration test results are presented in Table 2, reporting the estimated seven different co-integration equations corresponding to the seven financial innovation and access indicators utilized in this study. We used credit to the private sector as the dependent variable and same set of explanatory variables in all the estimated models but with a different financial innovation or access indicator in each case. All the results reported in Table 2 show existence of co-integrating relationships among the dependent and explanatory variables.

In Model 1, we used the value of mobile transactions as an indicator of financial innovation and Narayan (2005) critical values that are designed for small observations in the 30–80 range to assess the computed F-statistic. The result in the second column of Table 2 indicate an F-statistic of 9.31 which is higher than the critical upper bound value at 1% significance level, implying the presence of co-integration between credit to the private sector and its determinants. In Models 2 and 3, we used the number of mobile accounts and number of bank branches, respectively, as indicators of financial innovation and access. In Model 2, the results indicate an F-statistic of 7.97, while we obtain an F-statistic of 7.56 in Model 3, both of which are higher than the critical upper bound value at 1% significance level. Similarly, in Model 4, where we used the number of bank accounts as an indicator of access, we obtained an F-statistic of 5.33 which is higher than the critical upper bound value at 5% significance level. In Models 5–7, we interchangeably used value of ATM transactions as a share of GDP, the individuals using Internet as a percent of the population and number of mobile agents, respectively, as indicators of financial innovation. We obtained an F-statistics of 15.7, 28.01 and 23.47 indicating that long-run relationship exists between the dependent variable and the explanatory variables in all the three cases.

Table 3. Long-run model: the dependent variable is private sector credit to GDP

	Dependent variable: Private sector credit to GDP						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	Number of mobile accounts	Value of mobile transactions to GDP	Number of mobile agents	Value of ATM transactions to GDP	Bank branches	Number of bank accounts	Internet use
Trade openness	0.31 (2.05)**	0.29 (2.11)**	0.003 (0.62)	0.40 (3.25)***	0.08 (1.00)	0.30 (3.66)***	−0.02 (−017)
Exchange rate	0.60 (2.90)***	0.46 (2.34)**	0.38 (2.55)***	0.006 (2.94)***	−0.03 (−0.27)	0.19 (1.40)	0.50 (3.26)***
Consumer price index	−0.11 (−0.27)	−0.57 (−1.36)	−0.79 (−1.89)*	0.14 (0.30)	−0.61 (−2.17)**	−0.94 (−2.60)***	−0.95 (−2.39)**
Lending rate	0.01 (1.46)	0.005 (0.91)	−0.007 (−1.75)*	0.11 (1.02)	−0.11 (−2.10)**	−0.13 (−1.95)*	−0.24 (−2.51)***
Real GDP	0.05 (0.20)	0.13 (0.55)	−0.007 (−0.03)	0.001 (0.003)	0.03 (0.21)	0.01 (0.07)	0.03 (0.15)
Remittaces	0.32 (2.61)***	0.19 (1.73)*	−0.10 (−1.30)	0.18 (2.25)**	−0.07 (−1.28)	0.25 (2.19)**	0.07 (0.71)
Mobile transactions (value)		0.27 (2.64)***					
Mobile accounts (number)	−0.21 (−1.38)						
Mobile agent accounts			0.37 (4.32)***				
Bank branch					0.004 (7.64)***		
Automated teller machines				0.03 (0.51)			
Bank account						0.35 (4.23)***	
Internet use							0.50 (3.45)***
Dummy variable	−0.10 (−2.75)***	−0.13 (−4.12)***	−0.14 (−3.89)***	−0.17 (3.90)***	−0.05 (−2.29)**	−0.13 (−4.62)***	−0.14 (−4.11)***

Table 4. Results for the ECM (The dependent variable is private sector credit to GDP)

		Model 1 Number of mobile accounts	Model 2 Value of mobile transactions to GDP	Model 3 Number of mobile agents	Model 4 Value of ATM transactions to GDP	Model 5 Bank branches	Model 6 Number of bank accounts	Model 7 Internet use
Trade openness	$\Delta Topen_{t-1}$	0.08 (1.71)*	0.006 (2.31)**	0.08 (1.92)*	0.12 (2.86)***	0.05 (1.09)	0.10 (2.04)**	0.10 (1.86)*
Real GDP	$\Delta RGDP_{t-1}$	0.10 (1.42)	0.80 (1.25)	0.16 (2.51)***	0.07 (0.95)	−0.04 (−0.55)	0.79 (1.34)	0.05 (0.71)
Exchange rate	ΔER_{t-1}	0.03 (0.27)	0–0.02 (−0.17)	0.14 (1.35)	0.25 (2.14)**	−0.01 (−1.19)	0.02 (0.20)	0.19 (1.47)
Consumer price index	ΔCPI_{t-1}	0.33 (1.37)	0.16 (0.65)	−0.06 (−0.26)	−0.23 (−0.90)	0.04 (0.20)	−0.17 (−0.63)	0.50 (0.69)
Remittances	ΔREM_{t-1}	−0.05 (−1.89)*	−0.07 (−2.12)**	−0.05 (−1.80)*	−0.05 (−1.80)*	−0.07 (−1.87)*	−0.05 (−1.35)	−0.08 (−1.69)*
Lending rate	$\Delta Lend_{t-1}$	−0.14 (−2.24)**	−015 (−1.68)*	−0.09 (−1.61)	−0.16 (−2.64)***	−0.09 (−2.65)***	−0.12 (−1.87)*	−0.15 (−1.72)*
Mobile transactions (value)	$\Delta Mobv_{t-1}$		0.07 (1.27)					
Mobile accounts (number)	$\Delta Mobacc_{t-1}$	0.04 (0.80)						
Mobile agent accounts	$\Delta Magent_{t-1}$			−0.001 (−0.01)				
Bank branch	$\Delta Branch_{t-1}$					0.31 (0.72)		
Automated teller machines	ΔATM_{t-1}				0.08 (4.76)***			
Bank account	$\Delta Bankacc_{t-1}$						−2.34E−08 (−2.33)**	
Internet use	$\Delta Internet_{t-1}$							0.26 (1.95)*
Dummy variable	Dum_cap	−0.02 (−3.93)***	−0.09 (−2.95)***	−0.02 (−3.73)***	−0.03 (−5.46)***	−0.04 (−2.98)***	−0.03 (−4.37)***	−0.03 (−3.30)***
Error correction model	ECM(−1)	−0.22 (−2.63)***	−0.34 (−2.60)***	−0.33 (−3.32)***	−0.27 (−2.98)***	−0.30 (2.21)**	−0.39 (−2.77)***	−0.54 (−2.75)***

Table 5. Long-run model: The dependent variable is real GDP growth

	Dependent variable: Real GDP growth						
	Model 1 Number of mobile accounts	Model 2 Value of mobile transactions	Model 3 Number of mobile agents	Model 4 Value of ATM transactions	Model 5 Bank branches	Model 6 Number of bank accounts	Model 7 Internet use
Topen	−0.10 (−1.31)	−0.08 (−1.08)	−0.09 (−1.20)	−0.05 (−0.72)	−0.10 (−1.33)	−0.09 (−1.16)	−0.003 (−0.04)
CPI	−0.75 (−2.32)**	−0.80 (−2.55)***	−0.77 (−2.41)**	−0.68 (−2.04)**	−0.79 (−2.50)***	−0.87 (−2.61)***	−0.95 (−2.43)**
Rem	0.14 (2.20)**	0.15 (2.53)***	0.15 (2.53)***	0.09 (1.64)	0.12 (1.89)*	0.18 (2.41)**	0.20 (1.96)*
Cred	0.43 (2.49)***	0.46 (2.69)***	0.44 (2.88)***	0.51 (2.41)**	0.49 (2.56)***	0.44 (2.80)***	0.51 (2.11)**
GFCF	−0.31 (−1.46)	−0.32 (−1.59)	−0.30 (−1.45)	−0.31 (−1.39)	−0.12 (−0.65)	−0.34 (−1.56)	−0.31 (−1.24)
Pubdebt	0.37 (2.58)***	0.38 (2.76)***	0.37 (2.67)***	0.37 (2.66)***	0.23 (1.74)*	0.33 (−1.93)*	0.42 (2.22)**
Govcons	−0.72 (−1.96)**	−0.64 (−1.91)*	−0.58 (−1.81)*	−0.91 (−1.77)*	−0.88 (−2.31)**	−0.59 (−1.66)*	−0.53 (−1.03)
ER	−0.35 (−1.97)**	−0.26 (1.71)*	−0.29 (−1.83)*	−0.41 (−2.27)**	−0.27 (−1.78)*	−0.22 (−1.47)	−0.34 (−1.37)
MobV		−0.04 (−0.55)					
MobAcc	−0.02 (−0.52)						
MAgent			−0.03 (−0.63)				
Branch					−0.31 (−0.78)		
ATMV				−0.08 (−1.14)			
BankAcc						0.02 (0.22)	
Internet							−0.07 (−0.53)
Dum_cap	−0.06 (−1.48)	−0.08 (−1.84)*	−0.07 (−1.79)*	−0.06 (−1.49)	−0.06 (−1.80)*	−0.07 (−1.66)*	−006 (−1.31)

Table 6. Results for the ECM (the dependent variable is RGDP)

		Model 1 Number of mobile accounts	Model 2 Value of mobile transactions to GDP	Model 3 Number of mobile agents	Model 4 Value of ATM transactions to GDP	Model 5 Bank branches	Model 6 Number of bank accounts	Model 7 Internet use
Trade openness	$\Delta Topen_{t-1}$	0.14 (2.03)**	0.11 (1.71)*	0.15 (2.12)**	0.13 (2.03)**	0.14 (1.85)*	0.15 (2.10)**	0.12 (1.71)*
Consumer price index	ΔCPI_{t-1}	−0.61 (−1.37)	−0.18 (−0.36)	−0.54 (−1.21)	−0.69 (−1.66)*	−0.93 (−1.66)*	−0.52 (−1.12)	−0.87 (−2.31)**
Remittances	ΔREM_{t-1}	0.11 (2.14)**	0.10 (1.83)*	0.10 (2.01)**	0.11 (2.28)**	0.13 (2.14)**	0.12 (2.15)**	0.13 (1.91)*
Private sector credit	$\Delta CredP_{t-1}$	0.66 (2.06)**	0.02 (0.06)	0.71 (2.18)**	0.82 (2.66)***	0.93 (2.39)**	0.67 (1.85)*	0.76 (2.27)**
Gross fixed capital formation	$\Delta GFCF_{t-1}$	−0.36 (−1.41)	0.09 (0.35)	−0.35 (−1.44)	−0.37 (−1.60)	−0.29 (−0.86)	−0.33 (−1.24)	−0.40 (−1.25)
Public debt	$\Delta Pubdebt_{t-1}$	0.38 (2.01)**	0.20 (1.06)	0.42 (2.18)**	0.42 (2.37)**	0.39 (1.71)*	0.36 (1.91)	0.05 (0.25)
Government consumption	$\Delta ovCons_{t-1}$	−0.51 (−0.90)	−0.28 (−0.42)	−0.21 (−1.08)	−0.14 (−0.26)	−0.66 (−0.96)	0.23 (0.34)	0.27 (0.56)
Exchange rate	ΔER_{t-1}	−0.22 (−1.16)	−0.33 (−1.67)*		−0.23 (−1.28)	−0.22 (−1.01)	−0.20 (−1.20)	−0.35 (−1.68)*
Mobile transactions (value)	$\Delta Mobv_{t-1}$		0.27 (2.67)***					
Mobile accounts (number)	$\Delta Mobacc_{t-1}$	−0.04 (−0.49)					−0.14 (−0.90)	
Mobile agent accounts	$\Delta Magent_{t-1}$			−0.04 (−0.47)				
Bank branch	$\Delta Branch_{t-1}$					−0.29 (−0.26)		
Automated teller machines	ΔATM_{t-1}				0.10 (1.99)**			
Bank account	$\Delta Bankacc_{t-1}$							
Internet use	$\Delta Internet_{t-1}$							0.07 (0.26)

(continued)

Table 6.

		Model 1 Number of mobile accounts	Model 2 Value of mobile transactions to GDP	Model 3 Number of mobile agents	Model 4 Value of ATM transactions to GDP	Model 5 Bank branches	Model 6 Number of bank accounts	Model 7 Internet use
Dummy variable	Dum_cap	0.009 (0.57)	0.006 (0.39)	0.01 (0.77)	0.01 (1.23)	0.01 (0.62)	0.01 (0.65)	0.02 (1.12)
Error correction model	ECM(−1)	−0.87 (−4.05)***	−0.71 (−2.76)***	−0.89 (−4.07)***	−0.87 (−4.34)***	−0.74 (−2.62)***	−0.87 (−3.84)***	−0.95 (−4.22)***

5.2 Discussion of empirical results

In Table 3, we report results for the long-run model with different financial innovation and access indicators in Model 1 to Model 7, from columns 2–7. The results show that both financial innovation and access indicators are positive and significant in explaining financial depth. The coefficients of the value of mobile transactions, the number of mobile agents, the number of individuals using Internet, the number of bank branches and bank accounts are all positive and significant. The results further reveal that Internet use, number of mobile agents and value of mobile transactions have the highest impact on financial depth, while the number bank branches have the lowest impact. Although the coefficient of the number of bank branches is positive and significant, the size of the coefficient is near zero, showing that its contribution to financial depth is negligible with the advancement of the agency and mobile banking models. Similar results were found by Chinoda and Kwenda (2019) and Asongu and Odhiambo (2019).

Other important variables that bear the expected positive signs and are significant in at least four of the seven models in Table 3 are trade openness, remittances and the exchange rate. The relationship between remittances and financial depth is consistent with growth-enhancing theories while the result of the coefficient of trade openness is consistent with the demand side of financial development in which trade openness triggers increased demand of financial products and services. Our results corroborate previous work (Misati *et al.*, 2019; Ho and Iyke, 2018). The coefficient for the dummy for interest rate controls is negative and significant in all the seven models reported in Table 3. This result confirms that restrictions on prices, particularly interest rates, adversely affect loan growth. This result supports the financial repression theories of McKinnon (1973) and Shaw (1973).

Table 4 reports results for the short-term model and the ECM. The results show that all the coefficients of financial innovation and access indicators are not significant except value of ATM transactions, Internet usage and bank accounts. In contrast to the long-run model, the coefficient of the number of bank accounts is negative and significant in the short-run model. This would be explained by the fact that banks are no longer the main channels through which economic agents hold accounts. With the increasing number of non-bank financial service providers, consumers have diversified choices through which to manage their financial portfolio. The positive and significant relationship between bank accounts and financial depth in the long run may be explained by the fact that, over time commercial banks continue to form partnerships with non-bank financial providers and introduce new products including lending products. For instance, several commercial banks have collaborated with the main telecommunication companies to provide various mobile banking solutions including loan products.

The coefficient of remittances is significant in nearly all the models but unlike in the long-run models where the relationship is positive, in the short-run models remittances negatively affect financial depth. This would be due to the possibility of remittance flows initially leaning toward consumption before they lead to sufficient savings that can be channeled to investments or serve as collateral for their recipients. Similar results were found by Misati *et al.* (2019). Lending interest rate and the interest rate control dummy have a negative effect on financial depth as is the case for long-run models. Trade openness is also positive and significant consistent with the long-run models. The coefficient of the ECM is negative and significant in all the models as expected.

In Tables 5 and 6, we report the estimated long-run and short-run economic growth models. The results show that whereas credit to the private sector representing financial depth is positive and significant in all the seven reported models, none of the financial innovation or access indicators directly affects economic growth. This implies that the impact of financial innovation on economic growth is indirect through the financial deepening channel. The results also imply a dominance of the supply-leading hypothesis of the finance-

growth theory over the demand-pulling hypothesis given the results in Table 3 that show weak impact of GDP on financial depth. Thus, the results suggest that economic growth is reliant on the depth or extent of development of the financial sector. This result is consistent with previous studies (Bakar *et al.*, 2020).

The results also show that growth is negatively and significantly influenced by inflation and government expenditure. The results on the coefficient of government expenditure may be suggesting that most of the government expenditure is recurrent rather than investment. The coefficient of public debt is positive and significant in all the reported models, implying that parts of the debts in Kenya are growth-enhancing. Trade openness and gross fixed capital formation are not significant in explaining economic growth. The coefficient of remittances is positive and significant in nearly all the reported models in 5.4, implying that remittances not only deepen the financial system but also affects economic growth through other channels.

In Table 6, we report results for short-run analysis using real GDP as the dependent variable. The results indicate that credit to the private sector, value of mobile transactions and value of ATM transactions are important in explaining economic growth in the short run. However, number of mobile agents, bank branches and mobile accounts are not significant in economic growth in the short run. The coefficients for the ECM are all negative and significant as expected.

Results from Granger causality tests largely show unidirectional relationship from financial innovation indicators to financial depth regardless of the financial indicator used. The causality results indicate that the relationship between economic growth and financial depth is also largely unidirectional but sensitive to the indicators used [3]. The results obtained from this study are consistent with the state of finance-growth literature. However, specifically, the results relating to digital financial innovation and financial development are more applicable to African countries whose traditional financial systems excluded retail and low segments before DFS were adopted.

6. Conclusion

In the recent past, financial innovation has become an integral part of the modern financial system, accounting for nearly all the changes occurring in the financial system. Financial innovation is, however, heterogeneous and historical experiences, as well as empirical evidence show that it can lead to ambiguous outcomes on the financial system and economic growth. On the one hand, financial innovation of various forms enhances the efficiency of financial intermediation, provides new choices of financial products and services, facilitates trade and consumption and enhances financial inclusion with positive outcomes on growth. On the other hand, however, financial innovation that reduces asymmetric information increases risk-taking due to agency problems between bank owners and managers or because of lower costs of fragility with negative implications on the financial system and economic growth.

In this study, we demonstrate that there is a long-run positive relationship between financial innovation and financial depth in Kenya. The significant long-run relationship reflects efforts by various commercial banks to change their business models away from traditional banking strategies toward partnerships and strategic alliances with new non-bank financial players in Kenya. This finding provides a bridge for determining the causal effect of financial depth on economic growth. The results of the long-run economic growth models show that financial depth is positive and significant in explaining economic growth consistent with the finance-growth theories. However, none of the financial innovation indicators is significant in explaining economic growth, implying that financial innovation indirectly affects economic growth through the financial depth channel. The results further

indicate a positive relationship between remittances and economic growth both in the short run and in the long run, implying that remittances not only affect economic growth through the financial deepening channel but also through other channels. Results from Granger causality tests largely show unidirectional relationship from financial innovation indicators to financial depth regardless of the financial indicator used and from financial depth and innovation to economic growth.

It is evident that financial innovation largely captured by digitalized financial products and services is the new norm in the Kenyan financial system, especially given the possibility of entrenchment of customer habits under the enhanced digitalization drive following the COVID-19 pandemic. Our results show that Internet and mobile usage have the greatest impact on financial depth which, in turn, positively affects economic growth. This implies that rising Internet usage and adoption of mobile financial services is associated with increased financial depth and economic growth. A policy window exists for the Government to enhance financial intermediation efficiency by ensuring that all segments of the Kenyan population can cost effectively and easily access Internet services and mobile devices. This is particularly important for low-income earners who may not afford smartphones and Internet services.

Access to Internet services and usage of mobile devices largely depend on accessibility of other infrastructural facilities, in particular GSM network coverage, reliable electricity supply and smartphone devices. However, although most parts of Kenya can now access electricity, the cost of electricity has been increasing over time making it difficult for low-income earners to afford, besides the inefficiencies associated with regular blackouts. Moreover, given that smartphones that are appropriate for Internet use and mobile financial services are not only expensive but relatively new for most low-income earners, it is important that the Government and private sector stakeholders consider enhancing financial literacy aligned to smartphone technology.

Further, there is a need to consider and develop requisite policies to ensure that all segments of the Kenyan population, especially low-income earners, are not excluded from accessing online and Internet services. This calls for the need to invest in affordable infrastructure to enhance accessibility and connectivity of quality and reliable Internet and electricity supply. This study's findings confirm that extensive physical branch network is increasingly giving way to technologically driven service delivery channels. Investment in cost-effective financial innovative products will thus be a major determinant of the profitability of banks in future. It would also be instructive for the Government and private sector, mainly commercial banks, to design new programs that embrace finance and technology as the new frontier.

This study's main limitation is lack of both granular and aggregate time series and product specific data on indicators of digital financial products and services. The study, therefore, relied on mobile financial services data that are currently compiled by the Central Bank of Kenya in consultation with telecommunication companies. Further research covering possibilities of capturing data from other stakeholders such as FinTech companies would provide opportunities for enriching knowledge in this area.

Notes

1. Financial innovation is commonly defined to constitute new developments in the markets, institutions, instruments, processes and organizational forms, interaction with customers and regulations of the financial system. This includes whatever new developments that minimize costs, reduces risks or provides an improved product/service/instrument that better satisfies participants' demand within a financial system (Mollaahmetoglu and Ackali, 2019; Tahir *et al.*, 2018; Khraisha and Arthur, 2018; Arthur, 2017; Ajide, 2016; Ekpu, 2015; Blach, 2011; Mention and Torkkeli, 2012).

2. Results for unit root tests are provided in Table A3.
3. Granger causality tests are reported in Tables A1 and A2.

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Appendix 1

Table A1.
Granger causality tests: financial innovation and financial depth

Causality from financial innovation indicators to financial depth	F-statistic	Probability	Causality from financial depth to financial innovation indicators	F-statistic	Probability
BankAcc	12.17	0.001***	BankAcc	3.14	0.085*
MobV	17.43	0.001***	MobV	0.12	0.729
MobAcc	3.07	0.023**	MobAcc	1.19	0.344
MAgent	11.21	0.001***	Magent	0.5	0.483
ATMV	2.46	0.059*	ATMV	1.62	0.187
Branch	2.88	0.070*	Branch	1.06	0.357
Internet	3.04	0.064*	Internet	0.28	0.756

Appendix 2

Table A2.
Granger causality tests: financial depth and economic growth

Causality from financial depth and financial innovation indicators to economic growth	F-statistic	Probability	Causality from economic growth to financial depth to financial innovation indicators	F-statistic	Probability
Cred	9.06	0.004***	Cred	0.82	0.37
BankAcc	2.29	0.117	BankAcc	1.09	0.348
MobV	12.8	0.001***	MobV	0.17	0.677
MobAcc	1.83	0.174	MobAcc	5.81	0.006***
MAgent	2.04	0.145	Magent	0.22	0.8
ATMV	1.67	0.202	ATMV	1.72	0.193
Branch	0.72	0.493	Branch	2.06	0.143
Internet	3.27	0.012***	Internet	0.21	0.968

Appendix 3

Variable	At level	At first difference	Order of integration
RGDP	−6.39	–	I(0)
CRED	−1.15	−4.31	I(1)
TOPEN	−4.15	–	I(0)
ER	−2.07	−5.23	I(1)
Lend	−2.89	−4.27	I(1)
INT	−3.00	−7.69	I(1)
CPI	−3.10	−6.77	I(1)
REM	−2.09	−5.61	I(1)
MobAcc	−0.35	−7.46	I(1)
MAgent	−2.80	−6.14	I(1)
MobV	−3.75	−8.02	I(1)
ATMV	−3.22	−9.96	I(1)
BankAcc	−2.48	−4.08	I(1)

Table A3. Unit root tests

Corresponding author
Roseline Misati can be contacted at: nyakebwesi@gmail.com

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