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Research Article

From Connectivity to Creativity: Financial Development as a Catalyst of Africa's Digital Economy-Innovation Nexus

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Abstract

Innovation has emerged as an essential conduit for driving productivity, competitiveness and sustainability. However, its outcomes may not be fully realised without appropriate digital and financial systems. Considering this and motivated by SDG 9 and the African Digital Transformation Agenda 2063, this study contributes to knowledge by exploring the direct and synergistic effects of the digital economy and financial development on innovation across 29 African countries between 2011-2021 using the generalised method of moments estimation technique. Results show that the digital economy fosters innovation in Africa. Similarly, the individual components of the digital economy exert a positive influence on innovation, implying that innovation in Africa is stimulated by the combined effect of several digital elements that operate collectively to improve communication, efficiency, and the diffusion of knowledge. Additionally, the findings elucidate that well-developed financial systems are crucial for innovation, underscoring the pivotal role of financial development in the innovative ecosystem. Furthermore, the study presents that the contribution of the digital economy to innovation is fueled by financial development. Thus, financial development amplifies the impact of the digital economy on innovation, suggesting that integrated strategies targeted at developing the financial market and digital systems could lead to greater innovation outcomes. Hence, the study recommends that policies aimed at improving the digital economy and financial development should be addressed concurrently to foster innovation. Also, there is a need to expand access to investment, funding, and digital financial services to assist individuals and organisations in transforming digital potential into innovative outcomes.

Keywords: *Africa, Digital economy, Financial Development, Innovation*

1 Introduction

In an era characterised by rapid technological advancements, the digital economy has become a disruptive force that is changing global economic landscapes. The digital economy refers to the network of economic activities driven by the interconnection of businesses, data, devices, operations and individuals through technology. This

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encompasses online transactions across different sectors and technologies, including big data, mobile technology, the internet and information and communications technology (Javaid et al., 2024). This aligns with the G20 Digital Economy Ministers Meeting on July 22 2020 which provides a more expansive definition of the digital economy as "all economic activity reliant on, or significantly enhanced by the use of digital inputs, including digital technologies, digital infrastructure, digital services, and data; it refers to all producers and consumers, including government, that are utilising these digital inputs in their economic activities" (G20 DETF, 2020, p. 4). This indicates that the digital economy is more advanced and requires more than just using a computer and the extension of traditional economies to ensure value creation. This has emerged as an essential driver of the growth of economies and structural change.

In Africa, the digital economy is not just a strategic necessity but also holds the potential to revolutionise the continent. It represents more than just a technological advancement; it is a catalyst for inclusive growth, economic diversification and transformative development across the continent. This potential is underpinned by Africa's abundant resources, growing internet connectivity, subsea cable network, rapid mobile penetration, and a young and digitally inclined population, putting the continent in a unique position to become a leader among today's rising economies. As a result, the belief in the digital economy requires no leap of faith. It is a reality that needs to be embraced. Given this, the African Union has committed to growing the continent's already fast-growing digital economy through 'The Digital Transformation Strategy for Africa (2020-2030)', making digitally enabled socio-economic development a high priority (Union, 2020). This initiative ensures that African countries, businesses and individuals are digitally enabled by 2030. This digital force becomes a driving force for growth and innovation (Gaglio et al., 2022), which is consistent with the Sustainable Development Goal (SDG) 9, emphasising the need to "Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation". This stems from the fact that innovation is embedded in the very fabric of the digital economy and naturally contributes to the development of innovation output. Thus, the digital economy provides an unparalleled opportunity for accelerating innovation-driven development and avoiding the traditional phases of industrialisation. This ensures new ways of doing things and completely new forms of doing things, providing a revolutionary boost to innovation. Xu and Li (2022) highlight that the digital economy serves as a transformative force for innovation by reducing barriers to entry, enabling real-time data transmission, and promoting collaborative ecosystems. For instance, digital platforms reduce search and communication costs, providing companies with access to global talent pools and speeding up research and development (Yu et al., 2023). This highlights an interplay between the digital economy and innovation, which merits investigation.

While scholarly interest in the nexus between the digital economy and innovation has been increasing, notable gaps remain. The bulk of empirical research focuses on developed economies (Afonasova et al., 2019; Xu & Li, 2022; Zhou et al., 2024; Egbeleo & Sodokin, 2025), leaving Africa relatively underexplored. Also, within the African context, previous academic discussions have primarily examined the role of the digital economy on agricultural development (Wang et al., 2023), inclusive growth (Masłoń-Oracz et al., 2020), and economic growth (Dah et al., 2025). However, little attention has been paid to its influence on innovation output. Further, scholars who have attempted to explore this relationship often restrict their analysis to digital infrastructure such as mobile, internet, telephone and broadband subscriptions (Gaglio et al., 2022; Osei, 2024). While these indicators are important, this narrow focus provides a limited understanding of the broader digitalisation process, overlooking critical institutional, digital services, trade and technologies, and socioeconomic dimensions of the digital transformation, a gap that the concept of the digital economy addresses. In this light, this study advances knowledge by adopting a more comprehensive perspective through the construction of a multidimensional digital economy index. Unlike previous studies that rely solely on infrastructure indicators, this index integrates the digital services, trade and technologies and socioeconomic dimensions, providing a more nuanced understanding of how the digital economy fosters innovation.

Another issue discovered from the literature is that studies that have considered the relationship between digitalisation and innovation reveal conflicting evidence. For instance, Zhuo and Chen (2023) posit that digitalisation fosters innovation. In contrast, Liu et al. (2023) report no significant effect, except within a lag period of 2-3 years. This divergence suggests that the relationship could be potentially influenced by external fac-

tors. Consequently, scholars have begun considering the intervening role of human capital (Osei, 2024) on the digital-innovation nexus. Nevertheless, the potential role of financial development remains largely unexplored, leaving a gap in knowledge of how the financial systems strengthen or weaken this relationship. According to Shan et al. (2023), financial development lowers total risk and increases credit opportunities for the digital economy, ultimately benefiting innovation. Du and Wang (2024) add that financial development reduces loan interest rates, eases financing constraints, and expands funding sources for digital projects. This suggests that access to affordable and diversified financial services remains a key enabling factor for the development of the digital economy, which has implications for innovation. However, the extent to which the development of the financial market drives the digital economy is a question which requires investigation. Given this, this study contributes to the literature by shedding light on the following questions: First, what is the impact of the digital economy on innovation? Second, does financial development influence the digital economy-innovation nexus?

This study holds significant promise as it explores the interplay between the digital economy, financial development and innovation, particularly within the African context, where empirical evidence remains limited. First, the contribution of this study lies in its holistic approach to understanding the digital economy, which transcends the conventional digital infrastructure-focused perspective that predominates previous research. This multidimensional concept integrates technology, infrastructure, trade, institutional and socio-economic elements of an economy's digital ecosystem, which represents the digital progress of an economy. Second, another contribution of the study is the consideration of financial development into the digital economy-innovation framework. By considering the intervening role of financial development, the paper highlights that the enabling effect of financing in the digital-innovation nexus is crucial for government policies. This has significant ramifications for tackling structural issues that are specific to Africa, including limited financial access and inadequate digital infrastructure. It provides a foundation for harnessing the transformative potential of digitalisation for sustainable growth and innovativeness. This would enable Africa to better implement its digital transformation agenda. Third, the study offers insights for policymakers, stakeholders and financial institutions who want to develop integrated strategies that improve digital transformation and development of the financial system, fostering an atmosphere that is more conducive for innovation. The subsequent sections discuss the literature, method, findings and discussion, and conclusions and recommendations.

2 Literature review

2.1 Theoretical insights

The linkage between the digital economy and innovation can be explained by the diffusion of innovation theory. According to Rogers, the diffusion of innovation delineates how new ideas and concepts are adopted by individuals and organisations (Rogers, 1995; Miller, 2015). Schumpeter and Backhaus (1934) also highlight that innovation is a dynamic process that results in new combinations that can eventually take the shape of new products, services, or even creative production techniques. In the context of the digital economy, these dynamics determine how rapidly and effectively digital technologies translate into broader innovation outcomes. The digital economy, which is defined as "an economy based on digital technologies that covers mostly the sector of e-services and e-goods, and production process based on the use of digital technologies (Matyunina, 2019, p.27), speeds up innovation by lowering entry barriers, transaction costs, and knowledge flows (Bukht & Heeks, 2017). Thus, the diffusion of innovations in the digital economy, then, is the process by which an innovation spreads through communication and digital channels among members of the social system within a given time frame. Digital technologies increase relative advantage by speeding up and reducing the cost of processes, while simultaneously improving observability because they are highly visible and repeatable. This digitalisation is seen as a linchpin for an innovation-driven world (Dutta et al., 2022). This accelerates adoption rates and encourages innovation in both individuals and businesses.

Xu and Li (2022) further highlight that the digital economy has the ability to restructure the market economy, optimise resource allocation, promote the cross-border integration of innovation and entrepreneurship between

traditional and digital technology enterprises, expand the consumer market's development space, and significantly impact and change the conventional industrial organisation and mode of operation. For instance, digital inputs such as broadband access, mobile connection, and digital platforms serve as the primary facilitators of innovation by improving information flow and connectivity (Goldfarb & Tucker, 2019). These inputs reduce search and coordination costs by enabling businesses and individuals to more efficiently access markets, skills, and relationships (Brynjolfsson & Saunders, 2013). As information asymmetries reduce, businesses are better able to identify opportunities and experiment, which accelerates learning-by-doing and the dissemination of innovation ideas (Nambisan et al., 2019). These are the major advancements brought about by the digital economy. This suggests that the development of the digital economy provides an impetus for innovation development. However, to translate digital potential into realised innovation outcomes, financing plays a pivotal role. As Aghion et al. (2005) explain, the translation of digital opportunities into actualised innovation is contingent on the availability of finance. This perspective aligns with the financial development theory, which posits that financial development promotes growth through capital accumulation and technological progress by increasing the savings rate, mobilising and pooling funds, generating information about investments, facilitating and encouraging foreign capital inflows, and optimising capital allocation (World Bank, 2016). Lee and Shin (2018) add that the proliferation and commercialisation of digital innovations in established financial systems are made possible by financing and credit availability. Hence, weak financial structures can hinder this process, preventing potentially innovative digital initiatives. Ultimately, when digital inputs, reduced transaction costs, and financial support interact effectively, they foster the realisation of innovation outputs. These outputs include new products, processes, and business models that increase productivity and competitiveness. Horvey et al. (2024) add that financial development increases the innovative impact of the digital economy by boosting liquidity and risk-sharing mechanisms, like those found in fintech platforms. This enables more successful innovation as a result of digital progress.

2.2 Review of the digital economy and innovation

The digital economy represents an economy built on digital computing technologies, emphasising productivity gains that are either intrinsically digital or enabled by digital techniques (Su et al., 2024). This entails a paradigm shift in management from conventional manual or analogue techniques to digital systems and procedures. It encompasses a wide range of sectors from established industries such as media, telecommunications, and technology to emerging digital enterprises. This is seen as a key driver of innovation. In ways that were unimaginable only a few years ago, businesses may now use the digital economy to develop new business models and economic value, which in turn, stimulate innovation (Javaid et al., 2024). Gaglio et al. (2022) validate this perspective by highlighting that the digital economy has an inherent innovation capability and naturally contributes to the development of innovation output. Thus, the digital economy provides a revolutionary boost to innovation. Their empirical findings indicate that digital communication technologies, such as social media and business mobile phones for internet browsing, have a positive impact on innovation. Additionally, innovation that is dependent on the utilisation of these technologies has a positive impact on labour productivity. The results imply that public initiatives aimed at promoting equitable digitalisation should take into account the types of digital technologies that are most useful and accessible to small businesses, including those operating informally.

Aboal and Tacsir (2018) focus on the distinction between non-technological and technological innovation and conclude that ICT capital investment is gaining relevance as an important factor for the creation of innovation. Okolo et al. (2025) add that fixed broadband and secure internet servers are drivers of innovation. Through the lens of the regional innovation system, Zhou et al. (2024) examined the paradigm shift in spatial innovation dynamics brought about by the digital economy's explosive growth in 330 Chinese cities between 2011 and 2020. The findings indicate that the digital economy makes a substantial contribution to the production of innovation. Also, the digital economy's fortification of the regional innovation system, principally through its facilitation of integration into innovation networks and improvement of the innovation environment,

mediates this contribution. Bresciani et al. (2021) support the above argument and narrate that digitalisation helps eliminate the 'island phenomenon' and obstacles to information sharing between different business divisions and organisations by creating an information flow mechanism between enterprises and industries through connectivity technologies. Additionally, it promotes more open and collaborative innovation across companies as well as technology spillovers across industries. Zhou and Chen (2023) add that digitalisation overcomes the limitations of innovation and enhances absorption and transformation capacities to promote innovation due to its substantial cost-cutting and efficiency-boosting potential. Peng and Tao (2022) highlight that digital transformation significantly influences management innovation. Effective production management results from data collecting, analysis, and decision-making, which reduces market transaction costs, including search, transmission, and transportation costs. This, in turn, allows for greater investment in innovative projects.

Van Leeuwen and Farooqui (2008) expand the above narration by revealing that digitalisation fosters innovation for a number of reasons, which include the introduction of new products through e-commerce, the use of broadband internet to capture and process knowledge created elsewhere, and the management of knowledge flows both within and between businesses. According to their findings, digitisation has an indirect impact on productivity and significantly increases the likelihood of successful product innovation. Osei (2024) explored the role of digital infrastructure on innovation, indicating that innovation and digital infrastructure are positively related. Additionally, innovation is strongly influenced by the interaction between digital infrastructure and human capital, suggesting that digital infrastructure can indirectly foster innovation through the accumulation of human capital. The study suggests that policies aimed at improving digital infrastructure and human capital should be addressed concurrently to foster innovation. The impact of internet infrastructure on innovation in Latin American and Caribbean nations was examined by Zaballos et al. (2019). Research indicates a significant positive relationship between innovation (as indicated by trademark applications) and digital infrastructure (as indicated by investment in the telecom sector). However, using the trademark applications indicator revealed no discernible correlation between innovation and digital infrastructure. Pan et al. (2021) used data from 30 Chinese provinces between 2009 and 2015 to examine how technology infrastructure affects technological innovation capabilities. Their finding suggests that technology infrastructure and innovation have an inverted U-shaped relationship, suggesting that the influence of technological innovation on technology infrastructure may change from one of promotion to inhibition.

Insights from the literature show that the digital economy serves as a powerful innovation catalyst that may reduce costs, generate knowledge, and create new business models. However, much of the existing research ignores the broader relevance of the digital economy and tends to focus narrowly on digital infrastructure and technology. This study attempts to address this gap. Conflicting assertions are also made in the literature. Despite tremendous progress in our understanding of the connection between innovation and the digital economy, problems with contextual intervening factors persist. To address this, the current study examines the role of financial development as an intervening factor.

2.3 The role of financial development on the digital economy-innovation nexus

As earlier discussed, the nexus between the digital economy and innovation is not straightforward and is influenced by other factors such as financial development. Financial development, which is determined by the effectiveness of the banking industry, capital market depth, financial inclusion, and regulatory frameworks, plays a crucial role in fostering this relationship by reducing financing barriers, distributing resources as efficiently as possible, and encouraging the adoption of new technologies. This is because the digital economy involves high investment costs, and the lack of investment hampers its growth (Ullah et al., 2021). Hence, Hor et al. (2021) posit that a substantial amount of financial support is needed for digital technology's initial research, product development, and eventual commercialisation. This is where financial development becomes essential, as it reduces financing constraints in digital transformation. More so, the development of the financial market makes financial institutions more competitive, which lowers loan interest rates and expands loan channels and provides more funds for digital investment and innovation. He et. al. (2023) add that financial development

helps the supervision and management of high-quality projects and makes it easier for financial institutions to identify those with investment potential. It offers financial institutions valuable assistance, increasing the effectiveness of resource allocation and streamlining capital flow for digital transformation initiatives. Du and Wang (2024) support this argument and present that the effect of digitalisation on innovation shifts from negative to positive as banking and capital markets grow. This reveals that in the digital economy, the development of the financial sector is essential. This is because financial development has the capacity to reduce external finance constraint on the digital economy, enables risk diversification and aids in the allocation of funds towards digital projects. This ensures growth in the digital economy, ultimately influencing innovation. Li et al. (2024) agree with this assertion and state that digitalisation and financial development are mutually reinforcing. Digital platforms increase reach while financial development provides the required funding and risk-mitigation tools, which leads to increased acceptance of innovations. Despite these insights, empirical investigations to validate this relationship remain incipient. Given this, this paper extends knowledge by considering the intervening role of financial development on the nexus between the digital economy and innovation, particularly in the under-researched area, such as Africa. Figure A presents the pictorial illustration to enhance our understanding of the studied relationships.

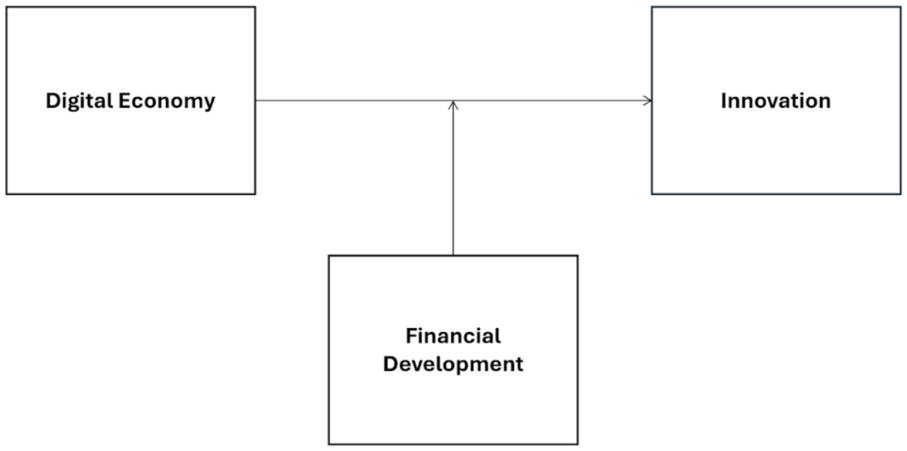

Figure A: Conceptual framework on the role of financial development on the digital economy-innovation nexus

3 Method

3.1 Sample and data

This paper employs multiple datasets from the World Development Indicators (WDI), the World Intellectual Property Organisation (WIPO), and the International Monetary Fund (IMF) to explore the direct and interactive effects of the digital economy and financial development on innovation in Africa. The study employs an unbalanced panel, and the selected sample, as informed by the available data, includes twenty-nine (29) countries between 2011-2021. The list of countries is presented in Table A1 in the appendix. We initiate the sample from 2011, given that data on innovation is largely unavailable for most African countries before this period and end the sample in 2021 because financial development, which is sourced from the IMF database, does not have data readily available beyond this point.

3.2 Variable definition

3.2.1 Explained variable

The explained variable, which is innovation, is measured using the innovation output index as defined by the Global Innovation Index (GII) provided by WIPO. We employed this proxy, given that we are interested in the results of innovative activities of a country for a given period within an economy. The GII report is of unique value to scholars and reliable for quantifying the innovation ecosystem of a country (Brás et al., 2023; Horvey & Odei-Mensah, 2024). According to WIPO, the innovation output index is measured using two main pillars, which are creative outputs (i.e., intangible assets, creative goods and services and online activities), and knowledge and technology outputs (i.e., knowledge creation, impact and diffusion) (Dutta et al., 2022). The innovation output index is normalised by WIPO to range between 0-100, and the higher the index, the higher the innovation outcome and vice versa.

3.2.2 Explanatory variable

To measure the digital economy, the study follows insights from and Pradhan et al. (2018) to construct a comprehensive index. This leads to a comprehensive evaluation of the digital economy index that takes into account digital trade, which consists of the import and export of ICT commodities. ICT products facilitate the use of advanced technologies and allow individuals to leverage their digital skills, hence fostering a robust digital economy (Pradhan et al., 2019). Furthermore, governments can import and export ICT goods and services to obtain innovative technology and information that may not be available, particularly in developing countries like Africa (Horvey et al., 2024). Accordingly, scholars posit that the use of ICT goods is an essential element of the growth of the digital economy. Another sub-indicator for evaluating the digital economy is the social impact. Compulsory education, internet usage and 'value-added medium- and high-tech manufacturing' are used to gauge this. Horvey et al. (2024) highlight that 'value-added medium- and high-tech manufacturing' encourages the creation of digital technologies, which are crucial for growing an economy's digital infrastructure. Furthermore, compulsory education and internet usage propel society's digital revolution by enhancing tech proficiency, providing access to digital services, and developing a workforce that is equipped with the skills required to use digital technology efficiently (Sun et al., 2024).

Another indicator of the digital economy is the growth of the digital infrastructure, which includes fixed broadband and telephone subscriptions, secure internet services and mobile cellular subscriptions. Further, we incorporate social support, calculated as 'service value per capita added'. The growth of these infrastructures ensures improved data transfer, communication, and high-speed internet connectivity, which are essential elements of the digital economy (Tzeremes et al., 2023). In this digital age, this interconnection facilitates a variety of digital services and social change, fostering innovation and technological progress, which are essential for skill development, innovation and growth. Furthermore, we create an index for the digital economy using Principal Component Analysis (PCA). According to Greenacre et al. (2022), PCA is a strong dimensional reduction technique which maintains the multidimensionality of a set of variables by reducing the number of indices to a small subset. It is important to highlight that before performing the PCA, a series of preliminary diagnostic tests were carried out, all of which were satisfied by our dataset. Specifically, we assess three conditions: (i) whether the digital economy variables constitute a suitable sample, (ii) whether the correlations among these variables are sufficiently strong, and (iii) whether both partial and overall intercorrelations are adequate for PCA. As presented in Table A2 in the appendix, the digital economy covariates exhibit high levels of correlation, confirming their suitability for inclusion in the analysis. Furthermore, the Bartlett's Chi-square test yields a value of 1452.951 with a p-value of 0.000, which is below the 0.05 significance level (Bartlett, 1954), thereby rejecting the null hypothesis of no intercorrelation among the digital economy variables. This provides a strong statistical justification for proceeding with the PCA. Additionally, Table 1 reports the Kaiser-Meyer-Olkin (KMO) statistics to describe the total and partial intercorrelations between the indicators. According to Kaiser (1974), the sample size used to measure the digital economy index is acceptable if the KMO statistic

is between 0.5-0.6, and good if the KMO is greater than 0.7. Hence, the overall KMO report, which is 0.732, shows that the digital economy sample is considered adequate and suitable for the empirical study. After completing the required tests, we create our digital economy index. The results of the eigenvalues and eigenvectors are presented in Tables 1 and 2, respectively. Figure B presents the scree plot, which shows the total number of digital economy components and the eigenvalue threshold of 1 for the component selection. In accordance with the Kaiser rule of eigenvalues greater than or equal to 1, we follow Del Carpio et al. (2017) to create the digital economy index using the first three components, as seen in Table 1. Together, they explain, 72% of the total variation. To evaluate the influence of each component, individual variables with substantial factor loadings were reduced using the 'orthogonal varimax rotation (kaiser off).' The contributions from each of the underlying components are then added to the aspects that were kept to create the digital economy index.

Table 1: Principal Components and eigenvalues of the digital economy index

Component	Eigenvalue	Difference	Proportion	Cumulative	KMO
Comp1	4.618	3.168	0.462	0.462	0.695
Comp2	1.451	0.282	0.145	0.607	0.660
Comp3	1.169	0.175	0.117	0.724	0.786
Comp4	0.994	0.468	0.099	0.823	0.764
Comp5	0.527	0.076	0.053	0.876	0.583
Comp6	0.450	0.070	0.045	0.921	0.806
Comp7	0.380	0.144	0.038	0.959	0.781
Comp8	0.236	0.100	0.024	0.983	0.784
Comp9	0.137	0.099	0.014	0.996	0.637
Comp10	0.038		0.004	1.000	0.750
Overall					0.732

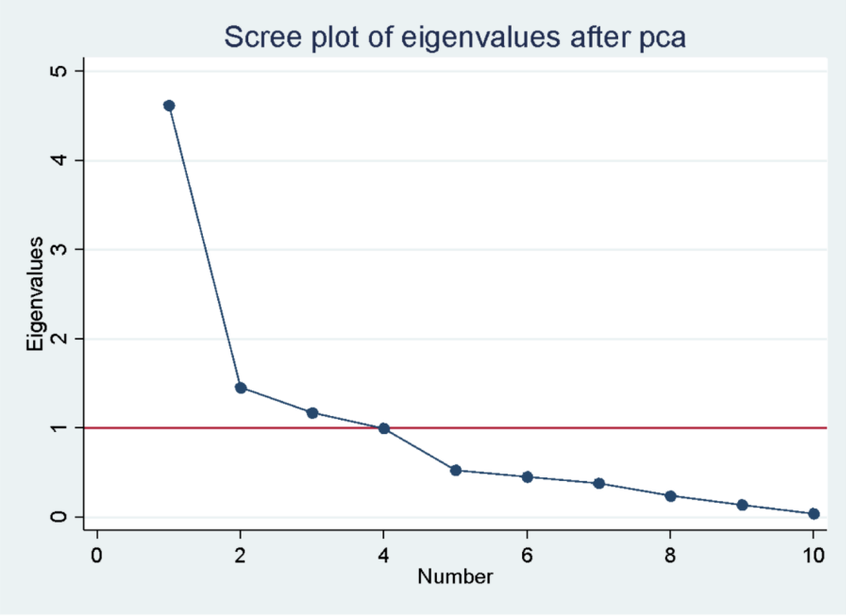

Figure B: Scree plot of the digital economy

Table 2: Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9	Comp10
Fixed broadband	0.380	-0.365	-0.165	-0.085	0.075	0.322	-0.134	-0.253	0.353	-0.610
Fixed telephone	0.378	-0.408	-0.136	-0.096	0.086	0.219	-0.180	0.170	0.166	0.720
Mobile	0.357	0.241	-0.172	-0.203	-0.245	-0.616	0.111	0.216	0.494	-0.031
Internet use	0.390	0.206	-0.073	-0.116	-0.410	0.025	0.086	-0.680	-0.338	0.185
Medium/high-tech man	0.154	0.620	-0.005	0.423	-0.134	0.417	-0.379	0.143	0.237	0.032
ICT exports	0.263	-0.210	0.148	0.653	-0.136	0.039	0.637	0.110	0.023	-0.010
ICT imports	0.258	-0.078	0.580	0.273	0.329	-0.428	-0.408	-0.243	-0.007	0.014
Services value added	0.421	-0.043	0.088	-0.144	-0.172	0.013	-0.176	0.550	-0.599	-0.267
Secure internet	0.174	0.279	0.577	-0.470	0.238	0.321	0.386	0.051	0.157	0.035
Compulsory education	0.259	0.292	-0.470	0.083	0.727	-0.078	0.187	0.035	-0.223	-0.005

3.2.3 Intervening variable

The main intervening variable, which is financial development, was drawn from the IMF database, which provides the financial development (FD) index (FD index). The IMF provides a comprehensive assessment of this variable by considering the depth, accessibility, and efficiency of financial markets and institutions (Svirydzneka, 2016).

3.2.4 Control variables

On the grounds of economic prudence, the study controls for economic growth, inflation, urbanisation and human capital, as informed by the literature (Omidi et al., 2020; Osei, 2024). These are essential to capture how the economic performance and (in)stability drives growth. GDP plays a key role in assessing a country's capacity for innovation. High GDP indicates that countries have more financial resources to fund innovative activities, both from the public and private sectors. This is measured using the 'GDP per capita (constant 2015 US$)'. The consumer price index is used to gauge inflation to determine how economic in/stability drives innovation (Osei, 2024). High or uneven inflation may stifle innovation. It erodes purchasing power, increases uncertainty, and makes returns on innovative activities less predictable, thereby discouraging innovation. Urbanisation is crucial for fostering innovation because it creates the perfect conditions for the development and dissemination of new ideas, technologies and business models. Human capital was measured as 'School enrollment, tertiary (gross), gender parity index (GPI)' to capture gender-inclusive human capital development. This was used to understand how equitable access to education fosters innovation. According to Østergaard et al. (2011), diversity in the development of human capital promotes innovation by encouraging cognitive variability and idea cross-fertilisation. When women have equal access to postsecondary education, societies benefit from a greater range of intellectual capacities and disciplinary involvement, which promotes the development and dissemination of innovative technologies (Klassen & Lamanna, 2009).

3.3 Empirical Strategy

The study first constructs a benchmark model to estimate the direct effects of the digital economy and financial development on innovation. Given this, we specify a functional model where innovation is a function of the explanatory and intervening variables.

$$INNOV_{it} = \beta_1 INNOV_{it-1} + \beta_2 DE_{it} + \beta_3 INF_{it} + \beta_4 GDP_{it} + \beta_5 URB_{it} + \beta_6 HC_{it} + \sigma_i + \vartheta_t + \varepsilon_{it} \quad (1)$$

$$INNOV_{it} = \beta_1 INNOV_{it-1} + \beta_2 FD_{it} + \beta_3 INF_{it} + \beta_4 GDP_{it} + \beta_5 URB_{it} + \beta_7 HC_{it} + \sigma_i + \vartheta_t + \varepsilon_{it} \quad (2)$$

Where INNOV denotes the innovation output index; DE denotes the digital economy; and FD denotes financial development; GDP denotes economic growth; INF denotes inflation; URB denotes urbanisation; HC denotes human capital; σ_i and ϑ_t captures the country-specific and time fixed effects; and ε_{it} denotes the idiosyncratic error term; i denotes the individual country, and t denotes the year.

To explore the intervening role of financial development on the digital economy and innovation nexus, the equation is expanded to include the interactive term, which is further presented in equation (3) below:

$$\begin{aligned} INNOV_{it} =& \beta_1 INNOV_{it-1} + \beta_2 DE_{it} + \beta_3 FD_{it} + \beta_4 \left(DE^{*} FD\right)_{it} + \beta_5 INF_{it} + \beta_6 GDP_{it} \\ &+ \beta_7 URB_{it} + \beta_8 HC_{it} + \sigma_i + \vartheta_t + \varepsilon_{it} \end{aligned} \quad (3)$$

Where (DE*FD) denotes the interactive term.

The net effect of equation (3) is further estimated as explained by Brambor et al. (2006), by taking the first derivative of the equation with respect to the digital economy. This is presented as:

$$\frac{\partial INNOV}{\partial DE} = \beta_2 + \beta_4 FD_{it} = 0 \quad (4)$$

The study employs a two-step system generalised method of moments (GMM) to estimate the model. The justification of this estimation technique is motivated by several factors. First, the unbalanced panel takes into account the cross-sectional and time dimensions, which is suitable for the GMM analysis, which preserves the cross-sectional dimension in the estimation process. Second, the cross-sectional dimension of the data (i.e., 29 countries) outnumber the period (i.e., 11 years). Third, there is the persistence of the dependent variable. In light of the dynamic nature of the model, the presence of the lagged dependent variable must be strongly correlated with its initial value, which is the situation in this model, reporting a correlation value of 0.9997. This is above the 0.8 threshold level for assessing persistence (Asongu & Odhiambo, 2021; Kunawotor, 2025). Further, the inclusion of the lagged dependent variable introduces endogeneity in the model, which is dependent on the error term, which is a function of the country fixed effects (Arellano, 2003). In this regard, the lagged dependent variable is treated as an endogenous regressor and is instrumented using its past levels to obtain a consistent and unbiased estimator. Also, the system GMM helps resolve endogeneity issues by taking into consideration unobserved heterogeneity. This is achieved by considering the time-invariant omitted variables, besides the creation of internal instruments to account for reverse causality. Reverse causality is said to exist between the digital economy and innovation (Acs & Audretsch, 2003; Pan et al., 2022; Osei, 2024). The fourth reason for selecting the two-step GMM is due to its ability to control for heterogeneity and cross-sectional dependence, which is ignored by the one-step GMM (Horvey et al., 2024). Further, as opposed to the difference GMM, the system GMM is based on 'forward orthogonal variations', which incorporates both the lagged level and difference as instruments, which is an enhanced version of the difference GMM (Blundell & Bond, 1998; Kunawotor, 2025).

The GMM is robustly specified if the narrative surrounding its specification contains a discussion of the related identification and exclusion restrictions. This technique helps in ensuring the robustness of the findings and defining the main variables. In other words, the identification phase in the specification exercise involves defining the endogenous, explanatory, and strictly exogenous variables. This relevance is supported by recent 'GMM-centric' literature (Asongu et al., 2020; Kunawotor, 2025). Following Roodman (2009), the years are treated as strictly exogenous, while the explained and control variables are treated as endogenous or predetermined. Given this, the independent variables, control variables and country dummies make up the instruments

for the orthogonal deviation equation and the levels equation. For the estimates without the interaction term, the lag structure is L(1/8), while the estimate with the interaction is L(3/6). The two-step system GMM was also performed with the Windmeijer finite-sample correction to two-step standard errors.

4 Empirical results and discussion

4.1 Summary statistics

The summary of the variables selected for the study is presented in Table 3. Innovation records an average value of 18.706 with a standard deviation of 6.272, showing high disparities of innovation among the selected sample. The average value suggests a low level of innovation in Africa, which is characterised by a low level of research and development, skills gap and inadequate infrastructure. The digital economy presents an average value of 0.000, and financial development has an average of 0.189, suggesting low levels of financial development. Economic growth, which is measured by 'GDP per capita (constant 2015 US$)', records an average of 2166.351 while the inflation rate is 6.012. The minimum and maximum values of inflation are -3.233 and 33.251, showing high variation for the study sample. The average for urbanisation is 41.00, showing that about 41% of the African population lives in urban areas, suggesting that despite Africa's ongoing urbanisation, a significant portion of the population still resides in rural areas. The average for human capital is 0.821, indicating a moderate accumulation of human capital across African countries. Since human capital is measured by 'School enrollment, tertiary (gross), gender parity index (GPI)', this average reflects both continued gender disparities in access to higher education and development in educational attainment. Table 4 presents the results of the correlation matrix, and we observe low correlations among the independent variables. This suggests that multicollinearity is not present in the model. This implies that the coefficient estimates of the independent variables are more reliable and consistent.

Table 3: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Innovation	18.706	6.272	2.050	35.000
Digital economy	0.000	2.149	-3.185	6.779
Financial development	0.189	0.128	0.064	0.593
Economic growth	2166.351	2196.429	255.078	10956.945
Inflation	6.012	5.692	-3.233	33.251
Urbanisation	41.00	16.681	10.915	74.261
Human capital	0.821	0.342	0.275	1.493

Table 4: Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Innovation	1.000						
(2) Digital economy	0.385	1.000					
(3) Financial development	0.301	0.749	1.000				
(4) Economic growth	0.337	0.900	0.803	1.000			
(5) Inflation	-0.080	-0.212	-0.095	-0.160	1.000		
(6) Urbanisation	0.162	0.497	0.367	0.397	-0.231	1.000	
(7) Human capital	0.103	0.688	0.683	0.729	-0.171	0.550	1.000

4.2 Pictorial insights

Before launching into the main empirical results, we first conducted a visual analysis of the main variable of interest, which includes the digital economy, financial development and innovation. Figure C illustrate a positive association between the digital economy and innovation, showing an uphill movement from left to right. This suggests that countries with more developed digital economies typically exhibit higher innovation. Thus, improved connectivity, development of digital infrastructure and use of digital technologies, trade and software are vital for promoting innovation in Africa. Similarly, we find that financial development is positively associated with innovation and the digital economy, as presented in Figures D and E. This implies that the growth of financial systems of an economy, which is characterised by improved financial intermediation, more credit availability and deeper financial markets, corresponds with growth in the digital economy and innovation. Thus, access to diverse financial services reduces the risks and constraints associated with innovation investment, thereby stimulating innovation and digital development. Further, financial development promotes the digital economy by fostering innovation, growth, and accessibility to digital resources. It facilitates the development of digital payment systems, which are essential to the online economy. Hence, a higher population of Africans, including those in Kenya, Ghana, the Democratic Republic of Congo, Lesotho, Tanzania, Egypt, Ethiopia, and Mozambique, can now interact digitally thanks to mobile banking services like M-PESA. Additionally, financial development facilitates credit acquisition for IT start-ups and digital entrepreneurs, creating opportunities for the growth of digital platforms, e-commerce, and online services within an economy. This illustrates the mutually reinforcing nature of the digital economy and financial advancement. Despite providing preliminary information about the relationship between these important factors, the bivariate results lack methodological soundness to draw reliable conclusions because of the problem of omitted variable bias, which must be addressed. To produce a more definitive and trustworthy conclusion, a thorough empirical study is carried out in the next sub-section.

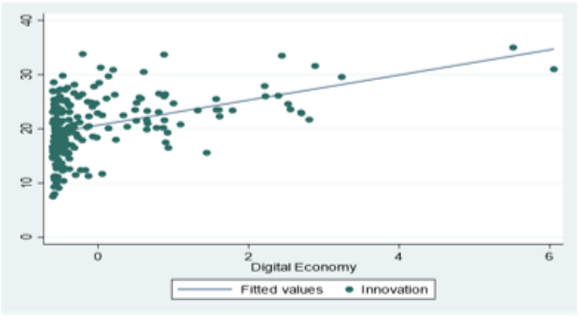

Figure C: Scatter plot of the digital economy and innovation

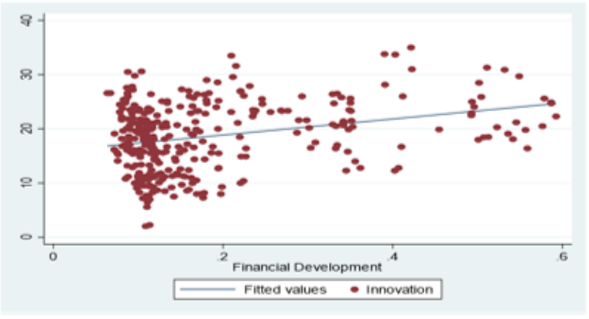

Figure D: Scatter plot of financial development and innovation

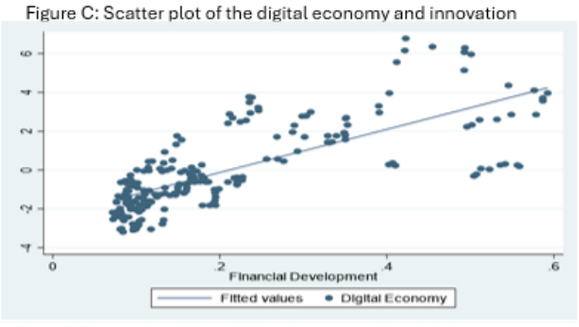

Figure E: Scatter plot of financial development and the digital economy

4.3 Direct and interactive effects of the digital economy and financial development on innovation

The main empirical findings of how the digital economy and financial development promote innovation are presented and discussed in this sub-section. Fourteen (14) models are estimated in Table 5. Models (1) to (10) present the results of the direct effects of the individual variables for creating the digital economy index, whereas Models (11) and (12) present the findings of the direct effect of the overall digital economy index and financial development on innovation. Model (14) provides the empirical results for the interactive term. The two-step system GMM, which is asymptotically more powerful than the one-step system GMM, was used for the analysis. The results in Table 5 further reveal that the assumptions guiding the use of GMM are met. This is evidenced by the insignificant values of the Hansen test and the second-order serial correlation (AR(2)). Also, the study findings show persistence in the outcome variable (i.e., innovation), which illustrates a significant positive coefficient estimate of its lag, which is consistent throughout the model. This indicates that current levels of innovation are driven by the innovation levels of the past. That is, the impact of innovation transcends its current year.

As discussed in Section 3.2.2, the digital economy index is created using several features. Therefore, the analysis begins by examining how each of these individual variables drives innovation. This provides deeper insight into how each of them supports the growth of innovation in Africa. The results are presented in Table 5, Models (1) to (10). The empirical evidence reveals that fixed broadband and fixed telephone subscriptions exhibit a positive influence on innovation, suggesting that these factors contribute to innovation in Africa. The positive relationship aligns with (Chen & Wang, 2023). This insight presents that fixed telephone plays a critical role and serves as the backbone of a country's communication infrastructure, facilitating institution coordination, economic operations and administrative procedures that support innovation. Also, Xu and Li (2022) emphasise that fixed broadband facilitates access to online platforms and digital resources that support innovation-related activities such as entrepreneurship, product development and research. This highlights the growing importance of internet connectivity in fostering innovation. In light of the above, the study suggests that governments and policymakers should not undervalue the necessity of maintaining and upgrading current communication infrastructure in addition to expanding broadband coverage, considering the significance of fixed telephone services. Strengthening fixed-line infrastructure can increase connectivity dependability, which is crucial for sectors like manufacturing, services, and education that rely significantly on innovation.

Similarly, mobile phone subscriptions, secure internet and internet use demonstrate a significant positive influence on innovation. This underscores how internet connectivity spurs innovation throughout the continent (Zhou et al., 2024). In Africa, mobile phones and internet connectivity have become central to the digital transformation agenda, giving access to individuals and organisations for innovativeness (Union, 2020). This has bridged communication gaps, reduced transaction costs and created opportunities for inclusive innovation, particularly in rural and underserved communities. In a similar vein, the significant positive impact of secure internet servers aligns with Okolo et al. (2025), who emphasise that access to secure internet servers provides the foundation to innovate. A secure digital environment encourages firms and individuals to engage in digital transactions and adopt innovative technologies without fear of cyber threats or data breaches. In a nutshell, the finding implies that innovation capacities would be further strengthened by increasing digital literacy, extending mobile broadband coverage, and incorporating digital technologies into corporate and educational ecosystems. This will encourage greater use of the digital infrastructure, which will in turn drive innovation.

Additional evidence in Table 5 highlights that medium and high-tech manufacturing, services value added, and compulsory education present a positive relationship. Nevertheless, they present no significant effect on innovation. The insignificant positive results show that although these factors foster innovation, their impact is weak and does not translate into any substantial innovation outcome. This underscores the need for more structural reforms in these areas, including enhancing education quality to fully realise the potential for fostering innovation in Africa. Further, ICT imports and exports reveal a significant positive relationship with innovation. This suggests that trade openness in ICT technologies and digital diffusion serves as an essential

conduit for driving innovation in Africa. The finding is consistent with (Cirera et al., 2016). According to Roger et al. (2022), ICT imports, which include computers and software, facilitate technology transfer and knowledge spillover, which increases the capacity of domestic businesses to innovate. Similarly, Bloom et al. (2016) contend that imported technology promotes information and knowledge sharing, which in turn fosters innovation. As a result, ICT imports serve as a crucial channel for businesses and institutions to incorporate contemporary technology into production processes, which fosters innovation in Africa. More so, the positive results for ICT exports reflect a country's growing technological capabilities. This association suggests that African economies are gradually transitioning from passive technology consumers to active participants in the global digital economy. This highlights the need to integrate Africa into the international ICT markets through policies that support technology-intensive imports and exports. To achieve this, there is a need to boost investment in digital infrastructure and skills development in the ICT sector. Such development will ultimately stimulate innovation on the continent.

Turning to the overall digital economy index, the results of the coefficient estimate reveal a significant positive relationship with innovation. This indicates the transformative potential of the digital economy in driving innovation in Africa. Thus, the development of the digital infrastructure, skills and social components leads to innovation in Africa. The outcome is consistent with scholarly evidence (Pan et al., 2021; Xu & Li, 2024). Zhou et al. (2024) support this finding and explain that the digital economy enables the creation of knowledge, adoption of technology, and transmission of ideas across borders, enabling businesses and individuals to develop new products, services, and processes. This aligns with the diffusion of innovation theory, which indicates that innovation is a dynamic process that results in new combinations that can eventually take the shape of new products, services, or even creative production techniques (Schumpeter & Backhaus, 1934; Rogers, 1995). In the context of the digital economy, these dynamics determine how rapidly and effectively digital technologies translate into more general innovation outcomes. Osei (2024) agrees with this finding and illustrates that digital technologies offer dynamic platforms that boost innovation ecosystems by facilitating better communication and teamwork. This implies that investments in the digital economy, including its components, can provide multiplicative effects and stimulate the innovation capacity of countries. As a result, African countries with nascent innovation could bridge this gap, promoting the digital infrastructure.

Further insight from the empirical shows a positive relationship between financial development and innovation among countries in Africa. The positive coefficient estimate implies that as financial systems deepen through increased financial intermediation, easier access to credit, or more liquidity, innovation outputs increase accordingly. This emphasises that a robust financial system promotes innovation and technological advancement (Pan et al., 2021). According to Du and Wang (2024), financial development increases loan availability and distribution, reduces transaction costs, and makes it easier for businesses and individuals to invest in innovative projects. This result supports Schumpeter's (1983) claim that financial intermediaries stimulate innovation by directing resources toward profitable ventures and mobilising savings. In Africa, where financial access remains a major bottleneck for entrepreneurs and small businesses, increased access to capital, risk-sharing arrangements, venture funding, and better financial institutions can foster innovation.

As discussed in the initial section of this paper, one of the pathways through which the digital economy stimulates innovation is financial development. This theoretical proposition is validated by the empirical findings, which show a significant positive interactive effect in Model 14, which underscores its synergistic effect. The net effect further supports this claim. This suggests that when the digital economy and financial development interact, they present a substantial impact on innovation. This supports the view of He et al. (2023) and Li et al. (2024), who present that financial development enhances the diffusion of innovation by reducing risk and funding constraints. The marginal effects at different percentiles of financial development (25%, 50%, 75% and 95%) and the margins plot confirming this effect are displayed in Table 6 and Figure F. The upward trend of the margins plot shows a synergistic effect in fostering innovation outcomes. This outcome is similar to the main results in Table 5, thereby reinforcing the argument that ensuring a sound financial system synergises with the digital economy to promote innovation. The empirical results imply that the digital economy does not operate in isolation; rather, its impact on innovation is amplified in environments with developed financial sys-

tems. This is because the digital economy involves high investment costs, and the lack of investment hampers its growth (Ullah et al., 2021). Hence, Hor et al. (2021) posit that a substantial amount of financial support is needed for digital technology's initial research, product development, and eventual commercialisation. Pan et al. (2021) add that financially developed economies provide the necessary credit, investment, and payment infrastructure to support digital transformation, enabling individuals and institutions to leverage technological tools for different endeavours, which in turn, promote innovation outcomes. The financial development theory aligns with this argument and states that financial development promotes growth through capital accumulation and technological progress by increasing the savings rate, mobilising and pooling funds, creating information about investments, facilitating and encouraging foreign capital inflows, and optimising capital allocation, which enables more productive innovation (World Bank, 2016). Hence, African countries interested in enhancing their innovation outcomes should adopt a coordinated approach that promotes both the digital economy and financial development.

Regarding the control variables, the study presents that inflation and innovation are negatively related. This implies that inflation impedes innovative activity in Africa. High inflation creates an atmosphere of economic uncertainty, which reduces purchasing power, drives up production costs, and reduces the incentives and capacity of businesses to invest in innovative projects. This outcome aligns with Osei (2024), who emphasises that inflation dampens innovation. This suggests the need to implement measures to ensure a stable macroeconomic environment for innovation. More so, economic growth, urbanisation and human capital mostly reveal a positive influence on innovation. This highlights the importance of macro and socio-economic development in innovation. Economic growth provides the institutional and financial resources needed to enable research, development, and adoption of new technologies (Osei, 2024). On the other hand, because markets, talent, and infrastructure are concentrated in metropolitan regions, urbanisation promotes innovation by fostering business competitiveness, collaboration, and information exchange (Xu & Li, 2024). The positive relationship for human capital reinforces the idea that a gender-balanced, educated and competent workforce is a key driver of innovation (Zhou et al., 2024). This is consistent with Romer's endogenous growth theory, which highlights the buildup of human capital as a driving force behind technical advancement (Schilirò, 2019).

Table 5: Marginal effects of the digital economy and financial development

Digital economy _at	dy/dx	Delta-method std. err.	Z	P>z	[95% conf. interval]	
25%	0.855	0.341	2.510	0.012	0.187	1.524
50%	0.904	0.336	2.690	0.007	0.246	1.563
75%	1.587	0.406	3.910	0.000	0.791	2.383
95%	1.068	0.330	3.240	0.001	0.421	1.714

4.4 Robustness analysis

For econometric prudence, we carried out two forms of robustness tests for the main empirical results. First, we employed the Driscoll-Kraay estimation technique, which accounts for heteroscedasticity, cross-sectional dependence and serial correlation (Driscoll & Kraay, 1998). The results of the direct and interactive effects are presented in Table 7. The results affirm the argument that the digital economy and financial development drive innovation, which is validated by the net effect, showing a positive and significant result. This consistency in the empirical results affirms the argument that the presence of a strong financial system and digital presence is crucial for driving innovation in African economies, thereby affirming the reliability and trustworthiness of the main findings.

The second form of robustness check offers a deeper understanding of the contextual dynamics shaping the relationship. This was done by conducting additional analysis according to the countries' income classification

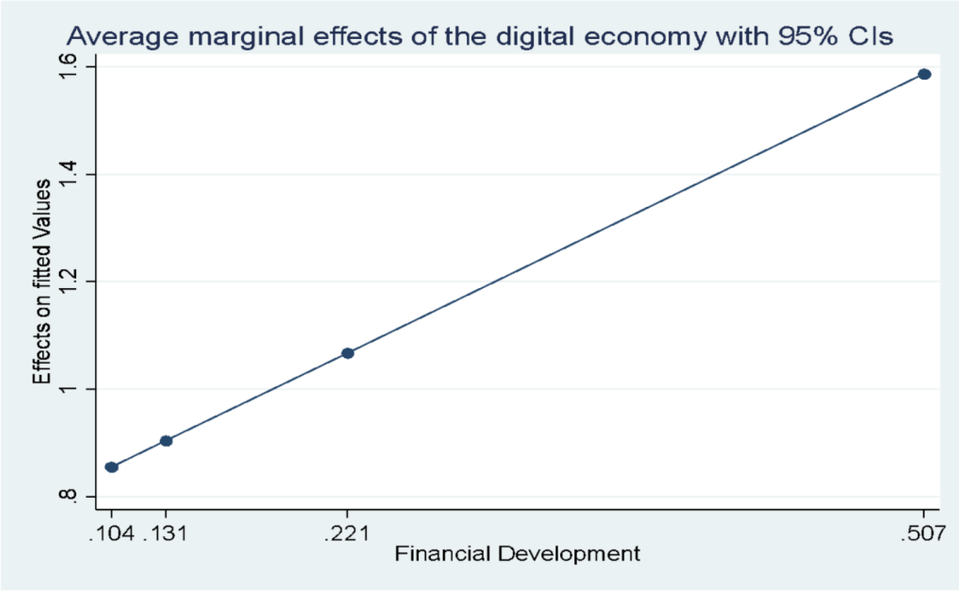

Figure F: Marginal effects of the digital economy and financial development

(i.e., low*, lower-middle†, and upper-middle‡ income countries) by including a triple interaction term. The findings in Table 8 reveal positive effects of the triple interaction, demonstrating significant effects when interacted with the middle-income countries (i.e., lower-middle and upper-middle income). This suggests that economies belonging to these income levels are well-positioned to harness the complementary effects of the digital economy and financial development on innovation in Africa. The outcome is expected given that middle-income economies experience a phase of rapid structural and technological changes, and improved financial systems compared to the low-income countries. Given this, policymakers should prioritise strengthening financial institutions to ensure that the digital economy successfully translates into innovation across socioeconomic levels. Efforts to expand digital infrastructure and promote financial inclusion are particularly crucial because lower- and upper-middle-income economies have the greatest potential for the synergy between finance and digitalisation. Regional cooperation and knowledge-sharing initiatives can also help low-income countries build the institutional and technological capacity needed to enjoy the same advantages of innovation-driven prosperity.

*Burkina Faso, Burundi, Ethiopia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Togo, Uganda
†Benin, Cameroon, Côte d'Ivoire, Egypt, Ghana, Guinea, Kenya, Morocco, Namibia, Nigeria, Senegal, Tanzania, Tunisia, Zambia
‡Algeria, Botswana, Mauritius, South Africa

Table 6: Direct and interactive effects of the digital economy and financial development on innovation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
L.innovation	0.410***	0.415***	0.348***	0.574***	0.396***	0.400***	0.416***	0.420***	0.398***	0.389***	0.359***	0.473***	0.354***	0.294***
	(0.065)	(0.055)	(0.063)	(0.049)	(0.052)	(0.053)	(0.059)	(0.067)	(0.053)	(0.059)	(0.060)	(0.070)	(0.061)	(0.073)
Inflation	0.110**	0.123**	0.093**	0.088**	0.107**	0.130**	0.126**	0.112**	0.108*	0.084*	0.028*	0.104**	-0.036	-0.035
	(0.051)	(0.052)	(0.043)	(0.042)	(0.047)	(0.049)	(0.045)	(0.049)	(0.053)	(0.059)	(0.045)	(0.050)	(0.046)	(0.051)
Economic growth	0.000	-0.000	-0.000	0.000**	0.000	0.001***	0.000	0.000	0.000	0.001***	-0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Urbanisation	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)	(0.040)
Human capital	1.332	1.408	3.180	2.522**	1.196	4.421***	0.700	0.704	0.585		-3.946***	0.926	-4.300***	-4.122**
	(2.250)	(2.197)	(2.476)	(1.089)	(2.051)	(1.263)	(1.965)	(1.363)	(2.149)		(1.267)	(2.094)	(1.393)	(1.449)
Fixed broadband	0.180*													
	(0.102)													
Fixed telephone		0.166*												
		(0.083)												
Mobile			0.069***											
			(0.023)											
Secure internet				0.000**										
				(0.000)										
Internet use					0.088***									
					(0.026)									
Medium/high tech						-0.006								
						(0.038)								
ICT_export							0.629***							
							(0.135)							
ICT_import								0.512**						
								(0.197)						
Services value added									0.000					
									(0.000)					
Compulsory education										0.106				
										(0.166)				
Digital economy											1.010***		1.070***	0.667*
											(0.314)		(0.326)	(0.371)
Financial development												3.374	3.570*	2.065
												(4.465)	(2.004)	(2.202)
DE*FD														1.815**
														(0.803)
Net effects														1.086***
Country/time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	221	221	221	221	220	174	208	208	221	189	138	221	138	138
No. of instruments	17	17	17	17	17	17	17	17	17	17	17	18	18	18
No. of countries	29	29	29	29	29	29	29	29	29	29	29	29	29	29
AR(1)	0.001	0.001	0.002	0.001	0.001	0.003	0.002	0.001	0.000	0.018	0.001	0.020	0.010	0.010
AR(2)	0.263	0.259	0.380	0.201	0.193	0.886	0.516	0.559	0.272	0.154	0.919	0.221	0.935	1.000
Hansen	0.115	0.105	0.098	0.080	0.077	0.070	0.141	0.098	0.098	0.139	0.222	0.081	0.224	0.177

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; DE represents digital economy; FD represents financial development

Table 7: Robustness analysis using the Driscoll and Kraay estimation technique

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Inflation	-0.023	-0.026	-0.085***	-0.002	-0.030	-0.013	0.025	-0.031	0.023	-0.015	-0.060	0.052	-0.072**	-0.067
	(0.036)	(0.035)	(0.029)	(0.037)	(0.044)	(0.039)	(0.043)	(0.051)	(0.034)	(0.027)	(0.040)	(0.034)	(0.039)	(0.044)
Economic growth	0.001***	0.001***	0.003***	0.002	0.001**	0.001*	0.001	0.001	0.001	0.001***	0.001**	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Urbanisation	-0.387**	-0.377**	-0.134	-0.681***	0.215	-0.688***	-0.183	-0.419***	-0.340***	0.055***	0.078***	0.051***	0.057***	0.055***
	(0.196)	(0.205)	(0.161)	(0.262)	(0.322)	(0.127)	(0.162)	(0.170)	(0.148)	(0.014)	(0.013)	(0.015)	(0.015)	(0.014)
Human capital	1.836	1.887	1.780	2.877	-0.553	-0.511	2.236	2.475	0.439	-5.714***	-0.603	-5.977***	-5.507***	-5.714***
	(2.015)	(1.953)	(2.197)	(1.991)	(1.617)	(1.999)	(1.696)	(1.854)	(1.897)	(2.234)	(1.627)	(2.143)	(2.192)	(2.234)
Fixed broadband	0.046													
	(0.095)													
Fixed telephone		0.043												
		(0.054)												
Mobile			0.083***											
			(0.015)											
Secure internet				0.000***										
				(0.000)										
Internet use					0.118**									
					(0.041)									
Medium/high tech						0.062***								
						(0.017)								
ICT_import							0.770***							
							(0.068)							
ICT_export								0.464***						
								(0.112)						
Services value added									0.000*					
									(0.000)					
Compulsory education										0.324***				
										(0.126)				
Digital economy											1.376***	1.420***	1.194***	1.466***
											(0.155)	(0.200)	(0.189)	(0.744)
Financial development												4.565***	4.464	3.503
												(0.844)	(2.918)	(2.872)
DE*FD														1.209
														(0.744)
Net effects														
Country/time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of countries	29	29	29	29	29	29	29	29	29	29	29	29	29	29
Observations	244	244	244	244	244	244	244	244	244	244	154	244	154	154
R-squared	0.632	0.732	0.505	0.687	0.566	0.657	0.658	0.736	0.634	0.564	0.552	0.453	0.557	0.560
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; DE represents digital economy; FD represents financial development

Table 8: Robustness analysis of the triple interaction effects

	(1) Low-income	(2) Upper-middle	(3) Lower-middle	(4) Lower-middle	(5) Upper-middle	(6) Upper-middle
L_innovation	0.748***	0.539***	0.441***	0.450***	0.574***	0.927***
	(0.037)	(0.160)	(0.105)	(0.103)	(0.081)	(0.048)
Digital innovation	-0.088**	0.047	0.848***	-0.008	0.742***	-0.744
	(0.382)	(1.103)	(0.384)	(0.589)	(0.316)	(0.549)
Financial development	1.417	-0.996	2.691	7.040*	1.916	11.468**
	(2.404)	(8.059)	(1.999)	(3.634)	(1.517)	(5.831)
Low-income	-0.349	-8.622				
	(11.174)	(31.621)				
Lower-middle			0.066	3.176**		
			(0.617)	(1.521)		
Upper-middle					0.499	23.888***
					(0.683)	(9.261)
DE*FD		-0.983		0.923		0.962
		(2.615)		(1.131)		(1.631)
DE*Low-income		-1.645				
		(9.587)				
DE*Lower-middle				-0.172		
				(0.514)		
DE*Upper-middle						6.442**
						(2.761)
FD*Low-income		5.011				
		(8.898)				
FD*Lower-middle				-11.529***		
				(4.854)		
FD*Upper-middle						0.848**
						(3.566)
DE*FD*Low-income		2.195				
		(2.198)				
DE*FD*Lower-middle				3.685**		
				(1.948)		
DE*FD*Upper-middle						17.343**
						(8.473)
Inflation	-0.022	0.002	-0.033	-0.017	-0.054	-0.044
	(0.055)	(0.069)	(0.047)	(0.049)	(0.038)	(0.049)
Economic growth	0.001**	0.001*	0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Urbanisation	0.061	0.043	0.018	-0.006	0.028	0.028
	(0.040)	(0.042)	(0.027)	(0.035)	(0.019)	(0.037)
Human capital	-2.237	-3.917	-3.120**	-0.972	-1.926	-5.828***
	(1.610)	(5.181)	(1.517)	(1.916)	(5.877)	(1.812)
Net effects						
Country/Time Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of countries	29	29	29	29	29	29
Observations	244	244	154	244	154	244
R-squared	0.632	0.732	0.505	0.687	0.566	0.657
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000
AR(1)	0.006	0.008	0.013	0.011	0.676	0.004
AR(2)	0.560	0.491	0.806	0.716	0.676	0.459
Hansen	0.067	0.121	0.121	0.085	0.316	0.459

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; DE represents digital economy; FD represents financial development

5 Conclusion and recommendations

5.1 Summary and conclusions

The digital economy has emerged as a disruptive force in Africa, which presents an immense potential to accelerate innovation in Africa. This represents more than technological advancement but reflects a paradigm shift in the spatial dynamics of innovation. As digital technologies such as fixed broadband and telephone, mobile phone, internet use, ICT import and exports, secure internet servers, among others, spread throughout

the continent, they have become essential catalysts for innovation. This aligns with the digital transformation strategy, which highlights that digitalisation is an essential force for innovation and growth, contributing to the attainment of Agenda 2063 and SDG 9, which seeks to 'Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation'. Motivated by this, this study contributes to knowledge by exploring the nexus between the digital economy and innovation in Africa, an area which has received limited attention. Additionally, this paper considers the intervening role of financial development on the relationship. It does so by considering a sample of 29 African countries between 2011-2021 using the two-step system GMM.

The empirical findings present that the digital economy plays a pivotal role in fostering innovation in Africa. Through improved connectivity, digital collaboration, and information access, the digital economy stimulates technological advancement and innovation outcomes. Similarly, the individual components of the digital economy index exert a positive influence on innovation. This implies that innovation in Africa is fueled by the combined impact of several digital elements that operate collectively to improve communication, efficiency, and the diffusion of knowledge and innovation. Further, the findings elucidate that a well-developed financial system is crucial for innovation, underscoring the pivotal role of the financial markets and intermediaries in the innovative ecosystem. Additionally, the study reveals a fascinating insight showing that the digital economy interacts effectively with financial development to promote innovativeness. Thus, financial development amplifies the impact of the digital economy on innovation. This illustrates that integrated strategies targeted at developing the financial market and digital systems could lead to greater innovation outcomes. Hence, there is a need to expand access to investment, funding, and digital financial services to assist individuals and companies in transforming digital potential into innovative outcomes.

5.2 Policy implications

The study's results have several implications for governments and policymakers seeking to promote innovation in their countries. This paper highlights the need for policymakers to prioritise investment in the digital infrastructure, internet, networks and data centres that foster accessibility and dependability, creating an enabling environment for innovation. More so, the empirical findings indicate that the digital economy interacts effectively with financial development to promote innovativeness. To harness this synergy, the development of the financial system, coupled with investment in the digital economy, should be prioritised by governments and policymakers to build a robust innovation ecosystem in Africa. Strengthening digital infrastructure without also improving financial access could restrict the potential benefits of technological progress. Therefore, initiatives that integrate digitisation with accessible financial policies, such as those that support digital banking, mobile payment systems, and fintech innovation, can create new opportunities for entrepreneurs and innovators. Additionally, enhancing regulatory frameworks to ensure the interoperability of digital and financial platforms would boost the system's effectiveness and credibility.

The following temporal directions are further suggested. In the short run, policymakers should focus on addressing immediate bottlenecks that hinder digital and financial integration. This includes expanding broadband networks, promoting affordable internet access, and ensuring cybersecurity, which will all help to sustain the momentum of digitally driven innovation. More so, improving right-of-way regulations can reduce the high costs of internet connectivity, which remain a barrier to digital participation in many economies. Establishing cybersecurity baselines is equally important to foster trust in online transactions and protect clients in an increasingly digitised financial landscape. Interoperability among mobile money platforms should also be prioritised to ensure that users and firms can transact seamlessly across networks, which will encourage inclusion and competition. Further, governments and regulators may increase financial inclusion by promoting digital financial services, expanding credit availability, and making venture capital more accessible, especially for start-ups and SMEs. Strong banking supervision, a stable rule of law, and information access are necessary for financial intermediaries to successfully identify productive innovations and allow small businesses and start-ups to access finance on more favourable terms.

Over the medium term, attention should be directed towards building a resilient digital and financial system

that can sustain and scale up innovation. Governments must invest in local and regional data centres to enhance data sovereignty, reduce latency, and assist emerging fintech and AI ecosystems. Strong digital public infrastructure, including national digital identification systems, will enable citizens and businesses to access and authenticate online services securely. Additionally, integrating digital skills education and training into national development goals can help businesses and individuals make effective use of digital resources. More so, governments should design policies that encourage private sector involvement and global digital collaboration in order to fortify the innovation ecosystem. Supporting technological clusters, innovation hubs, and digital start-ups could boost the advantages of the digital economy. Public initiatives to promote equitable digitalisation should be promoted, taking into account the kinds of digital technologies that are most useful and accessible to small businesses, including unofficial ones.

In the long run, policies should focus on establishing a digitally integrated and innovation-driven economic paradigm. Under the African Continental Free Trade Area (AfCFTA), this entails promoting the harmonisation of digital regulations across borders, facilitating pan-African financial networks, and expanding regional digital marketplaces. To maintain innovative capability, governments should also give top priority to expenditures in human capital development, green data infrastructure, and advanced research, especially in science, technology and engineering sectors. Digital governance systems must change over time to address ethical issues pertaining to algorithmic fairness, data privacy, and artificial intelligence. In the end, African economies will be able to fully utilise financial development as a catalyst for digital transformation and innovation-led growth if policies are coordinated and forward-looking, with an emphasis on transparency, inclusivity, and institutional reform.

5.3 Limitations and future directions

Despite the insightful contributions of the study, there are some limitations which provide avenues for future research. First, the study was limited to only 29 countries in Africa due to data availability constraints at the time of the study. Hence, future studies could expand the scope of the study by considering all African countries for a more representative argument. The study only considered the intervening role of financial development on the digital economy and innovation. Scholars could consider other intervening factors, such as institutional quality. Also, further research is required to understand the level at which financial development and the digital economy amplify or weaken innovation, employing the dynamic quantile regression or the threshold estimation techniques. Furthermore, in order to reveal contextual differences across African economies, future research could use country-specific or regional analyses, which would enhance the findings' empirical and policy relevance.

References

1. Aboal, D., & Tacsir, E. (2018). Innovation and productivity in services and manufacturing: The role of ICT. *Industrial and Corporate Change*, 27(2), 221–241.

2. Acs, Z. J., & Audretsch, D. B. (2003). Innovation and technological change. In *Handbook of entrepreneurship research: An interdisciplinary survey and introduction* (pp. 55–79). Springer.

3. Afonasova, M. A., Panfilova, E. E., Galichkina, M. A., & Ślusarczyk, B. (2019). Digitalization in economy and innovation: The effect on social and economic processes. *Polish Journal of Management Studies*, 19(2), 22–32.

4. African Union. (2020). *The digital transformation strategy for Africa (2020–2030)*.

5. Aghion, P., Howitt, P., & Mayer-Foulkes, D. (2005). The effect of financial development on convergence: Theory and evidence. *The Quarterly Journal of Economics*, 120(1), 173–222.

6. Arellano, M. (2003). *Panel data econometrics*. Oxford University Press.

7. Asongu, S. A., Nnanna, J., & Acha-Anyi, P. N. (2020). Finance, inequality and inclusive education in Sub-Saharan Africa. *Economic Analysis and Policy*, 67, 162–177.

8. Bartlett, M. S. (1954). A note on the multiplying factors for various χ^2 approximations. *Journal of the Royal Statistical Society: Series B (Methodological)*, 16(2), 296–298.

9. Bloom, N., Draca, M., & Van Reenen, J. (2016). Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity. *The Review of Economic Studies*, 83(1), 87–117.

10. Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

11. Brambor, T., Clark, W. R., & Golder, M. (2006). Understanding interaction models: Improving empirical analyses. *Political Analysis*, 14(1), 63–82.

12. Brás, G. R. (2023). Pillars of the Global Innovation Index by income level of economies: Longitudinal data (2011–2022) for researchers' use. *Data in Brief*, 46, 108818.

13. Bresciani, S., Ciampi, F., Meli, F., & Ferraris, A. (2021). Using big data for co-innovation processes: Mapping the field of data-driven innovation, proposing theoretical developments and providing a research agenda. *International Journal of Information Management*, 60, 102347.

14. Brynjolfsson, E., & Saunders, A. (2013). *Wired for innovation: How information technology is reshaping the economy*. MIT Press.

15. Bukht, R., & Heeks, R. (2017). *Defining, conceptualising and measuring the digital economy* (Development Informatics Working Paper No. 68). University of Manchester.

16. Chen, J., & Wang, J. (2023). The impact of broadband speed on innovation: City-level evidence from China. *Heliyon*, 9(1), e12831.

17. Cirera, X., Lage de Sousa, F., & Sabetti, L. (2016). *ICT use, innovation, and productivity: Evidence from Sub-Saharan Africa* (SSRN Working Paper No. 2866599). https://ssrn.com/abstract=2866599

18. Dah, D., Zahonogo, P., & Kaboré, P. F. (2025). Effects of the digital economy on economic growth in Africa: The role of human capital. *Cogent Economics & Finance*, 13(1), 2525485.

19. Del Carpio, X. V., Gruen, C., & Levin, V. (2017). *Measuring the quality of jobs in Turkey* (World Bank Report). World Bank.

20. Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, 80(4), 549–560.

21. Du, Z., & Wang, Q. (2024). The power of financial support in accelerating digital transformation and corporate innovation in China: Evidence from banking and capital markets. *Financial Innovation*, 10(1), 76.

22. Dutta, S., Lanvin, B., Wunsch-Vincent, S., & León, L. R. (Eds.). (2022). *Global innovation index 2022: What is the future of innovation-driven growth?* WIPO.

23. Egbeleo, E., & Sodokin, K. (2025). Digital transformation, institutional quality and productivity in Sub-Saharan Africa. *Cogent Economics & Finance*, 13(1), 2519924.

24. G20 Digital Economy Task Force. (2020). *Ministerial Declaration*. Retrieved from `http://www.g20.utoronto.ca/2020/G20SS_Declaration_G20_Digital_Economy_Ministers_Meeting_EN.pdf`

25. Gaglio, C., Kraemer-Mbula, E., & Lorenz, E. (2022). The effects of digital transformation on innovation and productivity: Firm-level evidence of South African manufacturing micro and small enterprises. *Technological Forecasting and Social Change*, 182, 121785.

26. Goldfarb, A., & Tucker, C. (2019). Digital economics. *Journal of Economic Literature*, 57(1), 3–43.

27. Greenacre, M., Groenen, P. J., Hastie, T., d'Enza, A. I., Markos, A., & Tuzhilina, E. (2022). Principal component analysis. *Nature Reviews Methods Primers*, 2(1), 100.

28. He, C., Geng, X., Tan, C., & Guo, R. (2023). Fintech and corporate debt default risk: Influencing mechanisms and heterogeneity. *Journal of Business Research*, 164, 113923.

29. Hor, S. C. T., Chang, A., de Oliveira, R. T., & Davidsson, P. (2021). From the theories of financial resource acquisition to a theory for acquiring financial resources how should digital ventures raise equity capital beyond seed funding. *Journal of Business Venturing Insights*, 16, e00278

30. Horvey, S. S., & Odei-Mensah, J. (2025). Innovative pathways in Africa: Navigating the relationship between innovation and insurance market development through linear and non-linear lenses. *Journal of the Knowledge Economy*, 1–35.

31. Horvey, S. S., Odei-Mensah, J., Moloi, T., & Bokpin, G. A. (2024). Digital economy, financial development and energy transition in Africa: Exploring for synergies and nonlinearities. *Applied Energy*, 376, 124297.

32. Javaid, M., Haleem, A., Singh, R. P., & Sinha, A. K. (2024). Digital economy to improve the culture of industry 4.0: A study on features, implementation and challenges. *Green Technologies and Sustainability*, 2(2), 100083.

33. Jolliffe, I. (2011). Principal component analysis. In *International encyclopedia of statistical science* (pp. 1094–1096). Springer.

34. Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39(1), 31–36.

35. Klasen, S., & Lamanna, F. (2009). The impact of gender inequality in education and employment on economic growth: New evidence for a panel of countries. *Feminist Economics*, 15(3), 91–132.

36. Kunawotor, M. E. (2025). Renewable energy consumption, government policy and income inequality dynamics: Empirical evidence from Africa. *Energy Reports*, 14, 1424–1433.

37. Lee, I., & Shin, Y. J. (2018). Fintech: Ecosystem, business models, investment decisions, and challenges. *Business Horizons*, 61(1), 35–46.

38. Li, J., Chen, L., Chen, Y., & He, J. (2022). Digital economy, technological innovation, and green economic efficiency Empirical evidence from 277 cities in China. *Managerial and Decision Economics*, 43(3), 616–629.

39. Liu, M., Li, C., Wang, S., & Li, Q. (2023). Digital transformation, risk-taking, and innovation: Evidence from data on listed enterprises in China. *Journal of Innovation & Knowledge*, 8(1), 100332.

40. Li, M., Meng, M., & Chen, Y. (2024). The impact of the digital economy on green innovation: The moderating role of fiscal decentralization. *Economic Change and Restructuring*, 57(2), 37.

41. Masłoń-Oracz, A., Ojiambo, J., & Kevin, O. (2020). Digital economy as a driver of sustainable and inclusive growth in Africa Case Study. In *The International Research & Innovation Forum* (pp. 605–616). Springer.

42. Matyunina, M. V. (2019). Diffusion of innovation in the digital economy. In *Selected Papers of the IV All-Russian Scientific and Practical Conference with International Participation "Information Systems and Technologies in Modeling and Control" (ISTMC'2019)* (pp. 26–32).

43. Miller, R. L. (2015). Rogers' innovation diffusion theory (1962, 1995). In *Information seeking behavior and technology adoption: Theories and trends* (pp. 261–274). IGI Global.

44. Nambisan, S., Wright, M., & Feldman, M. (2019). The digital transformation of innovation and entrepreneurship: Progress, challenges and key themes. *Research Policy*, 48(8), 103773.

45. Okolo, C. V., Susaeta, A., & Okorie, D. I. (2025). On the relationship between internet usage and technological innovation: Insight from world panel data. *Sustainable Futures*, 9, 100403.

46. Omidi, V., Shahabadi, A., & Mehregan, N. (2020). Innovation drivers in developing countries. *Journal of the Knowledge Economy*, 11(2), 707–720.

47. Osei, D. B. (2024). Digital infrastructure and innovation in Africa: Does human capital mediates the effect? *Telematics and Informatics*, 89, 102111.

48. Østergaard, C. R., Timmermans, B., & Kristinsson, K. (2011). Does a different view create something new? The effect of employee diversity on innovation. *Research Policy*, 40(3), 500–509.

49. Pan, W., Xie, T., Wang, Z., & Ma, L. (2022). Digital economy: An innovation driver for total factor productivity. *Journal of Business Research*, 139, 303–311.

50. Pan, X., Guo, S., Li, M., & Song, J. (2021). The effect of technology infrastructure investment on technological innovation A study based on spatial durbin model. *Technovation*, 107, 102315.

51. Peng, Y., & Tao, C. (2022). Can digital transformation promote enterprise performance? From the perspective of public policy and innovation. *Journal of Innovation & Knowledge*, 7(3), 100198.

52. Pradhan, R. P., Arvin, M. B., Hall, J. H., & Bennett, S. E. (2018). Mobile telephony, economic growth, financial development, foreign direct investment, and imports of ICT goods: The case of the G-20 countries. *Economia e Politica Industriale*, 45, 279–310.

53. Rogers, E. M. (1995). Diffusion of innovations: Modifications of a model for telecommunications. In *Die diffusion von innovationen in der telekommunikation* (pp. 25–38). Springer.

54. Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, Part 2), S71–S102.

55. Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. *The Stata Journal*, 9(1), 86–136.

56. Schilirò, D. (2019). The growth conundrum: Paul Romer's endogenous growth. *International Business Research*, 12(1), 1–10.

57. Schumpeter, J. A. (1983). *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle*. Transaction Publishers.

58. Shan, S., Mirza, N., Umar, M., & Hasnaoui, A. (2023). The nexus of sustainable development, blue financing, digitalization, and financial intermediation. *Technological Forecasting and Social Change*, 195, 122772.

59. Su, Z., Wei, J., & Liu, Y. (2023). Digital industrial platform development: A peripheral actor's perspective. *Technological Forecasting and Social Change*, 194, 122683.

60. Sun, C., Khan, A., Xue, J., & Huang, X. (2024). Are digital economy and financial structure driving renewable energy technology innovations: A major eight countries perspective. *Applied Energy*, 362, 122990.

61. Svirydzenka, K. (2016). *Introducing a new broad-based index of financial development* (IMF Working Paper No. 16/5). International Monetary Fund.

62. Tzeremes, P., Dogan, E., & Alavijeh, N. K. (2023). Analysing the nexus between energy transition, environment and ICT: A step towards COP26 targets. *Journal of Environmental Management*, 326, 116598.

63. Ullah, F., Sepasgozar, S. M., Thaheem, M. J., & Al-Turjman, F. (2021). Barriers to the digitalisation and innovation of Australian Smart Real Estate: A managerial perspective on the technology non-adoption. *Environmental Technology & Innovation*, 22, 101527.

64. van Leeuwen, G., & Farooqui, S. (2008). ICT investment and productivity. In *Information society: ICT impact assessment by linking data from different sources* (pp. 163–189). Eurostat.

65. Wang, J., Lin, Q., & Zhang, X. (2023). How does digital economy promote agricultural development? Evidence from Sub-Saharan Africa. *Agriculture*, 14(1), 63.

66. World Bank. (2016). Financial development [Background note]. In *Global Financial Development Report 2016*. Retrieved from `https://www.worldbank.org/en/publication/gfdr/gfdr-2016/background/financial-development`

67. Xu, J., & Li, W. (2022). The impact of the digital economy on innovation: New evidence from panel threshold model. *Sustainability*, 14(22), 15028.

68. Yu, W., Zhang, L., & Yang, C. (2023). The impact of the digital economy on enterprise innovation behavior: Based on CiteSpace knowledge graph analysis. *Frontiers in Psychology*, 14, 1031294.

69. Zaballos, A. G., Rodríguez, E. I., & Adamowicz, A. (2019). *The impact of digital infrastructure on the sustainable development goals: A study for selected Latin American and Caribbean countries* (Vol. 701). Inter-American Development Bank.

70. Zhang, J., Lyu, Y., Li, Y., & Geng, Y. (2022). Digital economy: An innovation driving factor for low-carbon development. *Environmental Impact Assessment Review*, 96, 106821.

71. Zhou, Q., Cheng, C., Fang, Z., Zhang, H., & Xu, Y. (2024). How does the development of the digital economy affect innovation output? Exploring mechanisms from the perspective of regional innovation systems. *Structural Change and Economic Dynamics*, 70, 1–17.

72. Zhuo, C., & Chen, J. (2023). Can digital transformation overcome the enterprise innovation dilemma: Effect, mechanism and effective boundary. *Technological Forecasting and Social Change*, 190, 122378.

APPENDICES

Table A1: List of countries

No.	Country	No.	Country
1	Algeria	16	Mauritius
2	Benin	17	Morocco
3	Botswana	18	Mozambique
4	Burkina Faso	19	Namibia
5	Burundi	20	Niger
6	Cameroon	21	Nigeria
7	Côte d'Ivoire	22	Rwanda
8	Egypt	23	Senegal
9	Ethiopia	24	South Africa
10	Ghana	25	Tanzania
11	Guinea	26	Togo
12	Kenya	27	Tunisia
13	Madagascar	28	Uganda
14	Malawi	29	Zambia
15	Mali		

Table A2: Correlation analysis for the digital economy index variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Bartlett Test
Note: Significant values are presented in parentheses											
(1) Fixed broadband	1.000										
(2) Fixed telephone	0.935	1.000									
	(0.000)										
(3) Mobile	0.428	0.458	1.000								
	(0.000)	(0.000)									
(4) Internet use	0.628	0.564	0.714	1.000							
	(0.000)	(0.000)	(0.000)								
(5) Medium and high-tech	-0.028	-0.040	0.338	0.381	1.000						
	(0.646)	(0.520)	(0.000)	(0.000)							
(6) ICT_export	0.483	0.483	0.233	0.379	0.170	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)						
(7) ICT_import	0.375	0.384	0.240	0.341	0.085	0.509	1.000				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.175)	(0.000)					
(8) Services value added	0.700	0.770	0.666	0.762	0.273	0.430	0.457	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
(9) Secure internet	0.145	0.135	0.237	0.329	0.151	0.033	0.344	0.362	1.000		
	(0.010)	(0.016)	(0.000)	(0.000)	(0.014)	(0.568)	(0.000)	(0.000)			
(10) Compulsory education	0.360	0.330	0.440	0.392	0.355	0.174	0.120	0.323	0.069	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.055)	(0.000)	(0.252)		
Chi (X^2) Statistics											1453.951
Chi (X^2) P-value											0.000