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Research Article

Policy Uncertainty, Digital Economy, and Financial Development: Reassessing the Innovation Dividend in African Economies

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Abstract

This paper examines how policy uncertainty conditions the digital economy-financial development-innovation nexus across 29 African economies (2011-2023). Despite significant progress in digitalisation and financial deepening, innovation performance remains heterogeneous. Using dynamic system GMM estimation, we find that digitalisation ($\beta = 0.728$) and financial development ($\beta = 8.748$) independently promote innovation, with positive complementarity ($\beta = 4.653$). However, policy uncertainty substantially weakens this synergy (triple interaction: $\beta =$ ˘$8.155, p < 0.05$). A one-standard-deviation increase in policy uncertainty erodes approximately 65% of the joint digital-finance innovation dividend. These findings highlight macroeconomic stability as a critical prerequisite for realising Africa's technological transformation.

Keywords: *Digital economy; Financial development; Policy uncertainty; Innovation, Africa*

1 Introduction

Innovation is a fundamental driver of economic growth, productivity and structural transformation (Schumpeter, 1983; Aghion & Howitt, 1992). It enables technological upgrading, diversification of production, and sustained competitiveness, objectives that are particularly critical for developing economies confronting persistent productivity gaps. Yet, despite progress in infrastructure and finance, innovation performance across many African economies remains below

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potential, reflecting structural and institutional frictions that constrain the translation of investment into technological upgrading (UNCTAD, 2023).

Over the past decade, Africa has undergone an extensive digital transformation. Broadband connectivity has expanded rapidly, and fintech ecosystems have flourished through platforms such as M-Pesa, Flutterwave, and Wave (McCrocklin, 2021; World Bank, 2024; GSMA, 2025). The African Union's Digital Transformation Strategy for Africa (2020–2030) envisions a fully integrated digital single market by 2030, premised on the belief that digitalisation can accelerate innovation, productivity, and inclusive growth (African Union, 2020). Complementarily, financial-sector reforms, ranging from mobile banking and capital-market deepening to fintech regulation, have aimed to mobilise resources for entrepreneurial activity and technological upgrading. Empirical research confirms that both the digital economy and financial development play vital roles in stimulating innovation and, when combined, can generate synergistic effects that magnify innovative outcomes (Levine, 2005; Nath et al., 2021; Osei, 2024). This variation across countries, however, suggests systematic conditioning factors beyond resource endowments. Such heterogeneity points to macroeconomic and institutional influences that shape the effectiveness of digital and financial systems in fostering innovation.

Existing literature extensively documents the effects of digitalisation and financial development on innovation (Levine, 2005; Nath et al., 2021) but largely overlooks how policy uncertainty conditions these relationships. This omission is consequential. Digital and financial infrastructures are inherently policy-sensitive, and the confidence of entrepreneurs and investors in leveraging them depends on predictable regulatory and macroeconomic environments. In unstable policy settings, digital investments may fail to translate into productive innovation, while financial deepening may channel resources into short-term, low-risk activities rather than high-risk, innovation-driven ventures. Recent evidence highlights this vulnerability: Afolabi (2023) show that policy uncertainty substantially weakens the positive influence of digital infrastructure on Africa's digital economy, and Emeka, Asongu and Ajah (2023) report that uncertainty undermines structural transformation. These findings resonate with the broader Schumpeterian insight that innovation thrives under stable expectations and credible institutions (Akcigit & Ates, 2021).

In the African context, no study has examined the triple interaction between digitalisation, finance, and policy volatility, a critical omission given the continent's pronounced macroeconomic instability. This study, therefore, situates policy uncertainty as a macroeconomic friction that potentially weakens the innovation benefits of digital and financial progress, an area of inquiry essential for understanding Africa's uneven innovation outcomes.

This paper addresses this gap by examining how policy uncertainty moderates the joint effects of digitalisation and financial development on innovation in 29 African economies from 2011 to 2023. Using a dynamic system GMM estimator with triple-interaction terms, the study assesses whether stable policy environments amplify the innovation returns from digital and financial development. The paper proceeds as follows: Section 2 develops the theoretical framework and hypotheses; Section 3 outlines the data sources and variable construction; Section 4 presents the empirical results; and Section 5 concludes with policy implications for sustaining Africa's digital and financial transformation.

2 Theoretical Framework and Model Specification

2.1 Conceptual foundations

Innovation, finance, and digitalisation are interdependent pillars of long-run growth. Within the Schumpeterian tradition (Schumpeter, 1934; Aghion & Howitt, 1992), innovation emerges from purposeful investment in new technologies and products. Endogenous growth models emphasise that such innovation depends on the efficiency with which financial systems mobilise savings, allocate capital, and manage risk (King & Levine, 1993; Levine, 2005). In this framework, financial development enhances the scale and efficiency of innovation by supplying liquidity for R&D and by improving information flows between innovators and investors.

Digitalisation reinforces financial–innovation linkages through three mechanisms: (1) reducing information asymmetries, (2) expanding market access, and (3) lowering transaction costs. It deepens innovation channels by facilitating the rapid diffusion of knowledge and by improving transparency in credit and product markets (Colombelli et al., 2024; Zhang et al., 2025). Digital platforms also strengthen financial inclusion by enabling small and medium enterprises to access formal credit and payment systems, thereby linking technological capability to financial resource mobilisation (Demirgüç-Kunt et al., 2008; Ricci et al., 2025). Consequently, the digital economy and financial development can be viewed as complements in promoting innovation.

However, this complementarity operates within an institutional context that determines risk and return expectations. The policy-uncertainty channel captures the degree of unpredictability in fiscal, monetary, or regulatory environments (Bloom, 2009; Baker et al., 2016). High uncertainty raises risk premia, delays irreversible investment, and depresses innovation incentives (Pastor & Veronesi, 2013). Specifically, uncertainty raises the real-options value of delaying irreversible R&D investments (Bloom, 2009), increases risk premia demanded by lenders, and shortens investment horizons, making long-gestation innovation projects unviable. In digital and financial ecosystems that rely on confidence and long-term planning, unstable policies can offset the benefits of digitalisation and finance by increasing transaction costs and reducing expected returns. Thus, the relationship between digitalisation, finance, and innovation is state-contingent positive under stability but attenuated when policy uncertainty rises.

2.2 Analytical framework

Let *INNOV* denote the level of innovation activity (e.g., patent applications, technology exports, or composite innovation index) in country i at time t. The baseline innovation function can be expressed as

$$INNOV_{it} = \alpha + \beta_1 DE_{it} + \beta_2 FD_{it} + \gamma' X_{it} + \varepsilon_{it} \tag{1}$$

where X is a vector of controls (human capital, economic growth, inflation, etc.). Following endogenous-growth reasoning, both DE and FD are expected to exert positive direct effects on *INNOV*.

To capture complementarity, the interaction term DE $\times$ FD measures how financial depth amplifies the innovation-enhancing potential of digitalisation. The moderating role of policy uncertainty is introduced through a triple-interaction term, DE × FD × PU, which tests whether uncertainty erodes or reverses the synergy between digital and financial development. Expanding equation (1) linearly yields

$$\begin{aligned} INNOV_{it} = &\beta_1 DE_{it} + \beta_2 FD_{it} + \beta_3 (DE_{it} \times FD_{it}) + \beta_4 (DE_{it} \times PU_{it}) \\ &+ \beta_5 (FD_{it} \times PU_{it}) + \beta_6 (DE_{it} \times FD_{it} \times PU_{it}) + \gamma X_{it} + \mu_i + \nu_t + \varepsilon_{it} \end{aligned} \tag{2}$$

where $INNOV_{it}$ is the innovation output index for country i in year t; DE_{it} and FD_{it} represent digital-economy and financial-development indicators; $PU_{i,t-1}$ is lagged policy uncertainty drawn from the World Uncertainty Index; X_{it} denotes controls variables (GDP per capita, inflation, human-capital, and urbanisation); and μ_i and λ_t represent country and time effects, respectively. The idiosyncratic error term is represented by $\varepsilon_i t$.

Coefficients $\beta_1, \beta_2 > 0$ reflect the direct effects of digitalisation and financial development individually on innovation; $\beta_4 > 0$ captures their complementarity joint digital-finance expansion magnifies innovation returns; and $\beta_7 < 0$ tests whether policy uncertainty diminishes that complementarity. The coefficient of interest, β_7, therefore, identifies how policy uncertainty conditions the joint digital–finance effect on innovation.

Building on the reasoning outlined above, the expected signs of the coefficients in equation (2) provide testable implications for how digitalisation, financial development, and policy uncertainty interact to shape innovation outcomes in African economies. The following hypotheses summarise these expectations and specify the direction and rationale for each effect.

H_1 (Direct Effects)

We expect $\beta_1 > 0$ and $\beta_2 > 0$ because digitalisation and financial development independently promote innovation. Digital technologies enhance knowledge diffusion and reduce coordination costs, while financial deepening provides liquidity and risk-sharing mechanisms that support research and entrepreneurial activity (Levine, 2005; Nath et al., 2021). The magnitude of these effects is likely higher in economies with greater absorptive capacity and institutional quality, where technological spillovers and credit allocation are more efficient.

H_2 (Complementarity Effect)

The interaction term $(DE \times FD)$ is expected to have a positive coefficient $(\beta_4 > 0)$, reflecting synergy between digital and financial systems. A well-developed financial sector enables firms to invest in digital infrastructure, while digitalisation increases the efficiency and reach of financial services. Together, these mutually reinforcing mechanisms yield an "innovation dividend" where the combined effect exceeds the sum of their individual contributions.

H_3 (Policy-Uncertainty Moderation)

We expect $\beta_5 < 0$ and 6<0 because policy uncertainty amplifies the perceived riskiness of both digital and financial investments. Specifically, uncertainty raises the real-options value of delaying irreversible R&D projects (Bloom, 2009), increases risk premia demanded by lenders, and shortens investment horizons (Pastor & Veronesi, 2013). This effect should be strongest in countries with weaker institutional quality or volatile fiscal regimes, where frequent policy reversals erode investor confidence.

H_4 (Policy-Uncertainty and Digital–Finance Synergy)

The triple-interaction term $(DE \times FD \times PU)$ is expected to yield a negative coefficient $(\beta_7 <$

0), indicating that rising policy uncertainty weakens the complementarity between digitalisation and finance. In uncertain environments, even robust digital and financial systems may fail to reinforce each other because firms shift toward short-term, low-risk activities. Hence, the potential innovation dividend from digital–finance integration is conditional on macro-policy stability and credible governance frameworks.

This analytical structure provides a coherent framework for reassessing the innovation dividend in Africa's digital economy and for evaluating the institutional conditions under which technological and financial progress translate into sustainable innovation outcomes.

2.3 Dynamic structure and estimation approach

Innovation processes display persistence due to knowledge accumulation and network effects. To account for this, the dynamic specification includes a lagged dependent variable:

$$INNOV_{it} = \rho INNOV_{i,t-1} + RHS(2) + \varepsilon_{it} \tag{3}$$

where $|\rho| < 1$ ensures stability. The presence of the lagged term and potential endogeneity among DE, FD, and PU motivates the use of a system Generalised Method of Moments (GMM) estimator (Arellano & Bover, 1995; Blundell & Bond, 1998). System GMM combines equations in levels and first differences, exploiting internal instruments to address simultaneity and omitted-variable bias while controlling for unobserved heterogeneity. All right-hand-side variables, except for strictly exogenous controls, are treated as potentially endogenous and instrumented with appropriate lags in levels and first differences. To limit instrument proliferation and maintain efficiency, the number of instruments is collapsed following Roodman (2009).

Diagnostic tests, the Arellano-Bond AR(2) test for serial correlation and the Hansen or Sargan test for over-identifying restrictions, verify model validity. Marginal-effects are later employed to quantify how varying levels of policy uncertainty alter the marginal returns of digitalisation and financial development on innovation.

3 Data and Variable Construction

3.1 Data sources and coverage

The empirical analysis uses an unbalanced panel of 29 African economies spanning 2011–2023, selected according to data availability for innovation indicators, financial development, digital-economy metrics, and the World Uncertainty Index (WUI). Countries include both lower- and upper-middle-income economies across sub-regions, ensuring heterogeneity in digital infrastructure and financial depth.

Data were compiled from multiple reputable sources:

Table 1: Data Categories and Sources

Category	Indicator Source	Principal Variable(s)
Innovation	World Intellectual Property Organization (WIPO)	Global Innovation Index (GII) Innovation Output Index from WIPO, capturing outcomes of national innovative activity via two pillars: creative outputs and knowledge and technology outputs, reported on a 0–100 scale where higher values indicate stronger innovation performance (Dutta et al., 2022; Brás et al., 2023).
Digital Economy	International Telecommunication Union (ITU), World Bank World Development Indicators (WDI); GSMA Mobile Connectivity Index	Composite digital-economy index incorporating (i) digital trade (imports & exports of ICT goods and services); (ii) social impact (computers' education internet usage, and value-added medium- and high-tech manufacturing); (iii) digital infrastructure (fixed broadband and telephone subscriptions, secure internet servers, mobile-cellular penetration); and (iv) social support (service-industry value added per capita) all aggregated using PCA following Sun et al. (2024) and Horsey et al. (2024).
Financial Development	IMF Financial Development Database (Svirydzenka, 2016)	Financial-development index combining depth, access, and efficiency of banking and market systems.
Policy Uncertainty	World Uncertainty Index (Ahir, Bloom & Furceri, 2022)	Quarterly WUI, averaged annually, capturing textual frequency of "uncertainty" in country reports.
Controls	WDI; World Governance Indicators; UN Human Development Reports	GDP growth, human-capital index, urbanisation, and inflation rate.

3.2 Variable construction

3.2.1 Innovation performance (INNOV)

The dependent variable, innovation, is proxied by the Innovation Output Index from the Global Innovation Index (GII) compiled by WIPO. This metric focuses on realised outcomes of a country's innovative activity in a given period, which aligns with the study's emphasis on measurable results. The index aggregates two pillars: creative outputs that include intangible assets, creative goods and services, and online activities, and knowledge and technology outputs that cover knowledge creation, impact, and diffusion. WIPO scales the index from 0 to 100, with higher values indicating stronger innovation outcomes. The GII is widely used in academic work and is considered a credible basis for quantifying national innovation ecosystems (Dutta et al., 2022; Brás et al., 2023).

3.2.2 Digital economy development (DE)

To measure the digital economy, the study follows Horvey et al. (2024) in constructing a comprehensive composite index that captures four dimensions of digital transformation:

1. Digital trade: imports and exports of ICT goods and services, reflecting the extent of technology diffusion and access to advanced digital tools. ICT trade enhances technological learning and international spillovers (Horvey et al., 2024).

2. Social impact: compulsory-education enrolment, internet-usage rate, and value-added medium- and high-tech manufacturing. These proxies capture human-capital readiness and industrial digitalisation (Sun et al., 2024).

3. Digital infrastructure: fixed-broadband and telephone subscriptions, secure internet servers, and mobile-cellular penetration indicators of connectivity and communication capacity (Tzeremes et al., 2023).

4. Social support: service-industry value added per capita, representing the service backbone that sustains digital activity and knowledge-based exchange.

The indicators are normalised (0–1 scale) and aggregated using Principal Component Analysis (PCA) with orthogonal varimax rotation. Following Greenacre et al. (2022), PCA reduces dimensionality while preserving multidimensional variance. As shown in Table 2, the first component (Comp1) recorded an eigenvalue of 4.618 and explained 46.2% of total variance, exceeding the Kaiser criterion (>1) and confirming its suitability as a representative index. The Kaiser–Meyer–Olkin (KMO) measure of 0.732 indicates sampling adequacy, and the scree plot (Figure 1) shows a distinct elbow at component 2, with eigenvalues declining sharply from 4.618 to 1.451, validating the retention of only the first component (Kaiser criterion: eigenvalue > 1). The highest loadings in Comp1 correspond to internet use (0.390), services value-added (0.421), fixed broadband (0.380), and fixed telephone subscriptions (0.378), demonstrating that access, connectivity, and service-sector digitisation jointly define Africa's digital economy structure (see Table 3). This multidimensional construction reflects not only infrastructure but also trade, education, and industrial digitalisation, thereby offering a richer representation of Africa's digital transformation than conventional single-indicator measures.

Table 2: 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	0.223	0.145	0.607	0.660
Comp3	1.169	0.175	0.117	0.724	0.786
Comp4	0.969	0.468	0.069	0.823	0.764
Comp5	0.537	0.076	0.093	0.876	0.383
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	0.989	0.647
Comp10	0.038	–	0.004	1.000	0.750
Overall					0.752

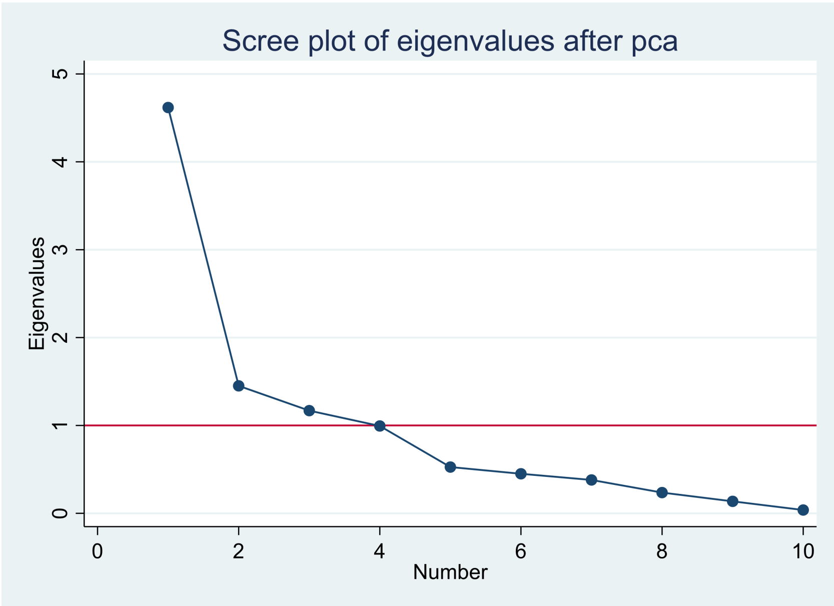

Figure 1: Scree plot of the digital economy

3.2.3 Financial development (FD)

Financial development is captured through the IMF Financial Development Index, which combines measures of financial depth (private-credit-to-GDP, stock-market capitalisation), access (bank accounts per 1,000 adults), and efficiency (interest-rate spread, turnover ratio). Where data gaps exist, domestic credit to private sector (% GDP) serves as a robustness proxy. Both variables are logged to reduce skewness.

3.2.4 Policy uncertainty (PU)

Policy uncertainty is measured by the World Uncertainty Index (WUI) developed by Ahir et al. (2022). The WUI quantifies the relative frequency of "uncertainty" in the Economist Intelligence Unit country reports relative to total world count, normalized by global averages. The index is demeaned and standardised by its global mean and standard deviation to allow interpretation of coefficients as effects of one-standard-deviation changes in uncertainty. Higher values indicate greater textual emphasis on economic, political, or regulatory unpredictability.

3.2.5 Control variables (X)

Control variables account for additional factors influencing innovation. Human capital (HC) is measured using the education index from the UN Human Development Reports. Economic development (GDPpc) is represented by the logarithm of real GDP per capita. Urbanisation and inflation (INF), measured as the annual percentage change in consumer prices, are also included. All continuous variables were mean-centred prior to generating interaction terms to reduce multicollinearity in the $DE \times FD \times PU$ specification.

Table 3: 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

4 Empirical Results and Discussion

4.1 Descriptive Statistics and Correlation Structure

Table 4 presents descriptive statistics for all variables across 29 African economies over 2011–2023. The mean innovation index is $18.7(SD = 6.27)$, with values ranging from 2.1 to 35.0, indicating wide heterogeneity across countries. The digital economy index (standardised via PCA) has a mean of 0.00 and a standard deviation of 2.15, implying substantial variation in digital infrastructure development. Financial development averages 0.189, while lagged policy uncertainty (PU) has a mean of $0.292(SD = 0.202)$, reflecting moderately high uncertainty across the continent.

The correlation matrix (Table 5) shows that innovation is positively correlated with the digital economy $(r = 0.329)$, financial development $(r = 0.257)$, and policy uncertainty $(r = 0.224)$. While the bivariate correlation between innovation and policy uncertainty is positive (r = 0.224), this likely reflects confounding by omitted variables such as economic development. Countries with higher innovation may also experience more policy debate and thus higher measured uncertainty. The conditional effect, controlling for other factors, is examined in the multivariate analysis below. Correlations between DE and FD ($r = 0.695$) and between DE and urbanisation ($r = 0.712$) confirm the expected complementarity between digitalisation, finance, and urban transformation. Inflation remains weakly correlated with all innovation drivers ($r < 0.05$), suggesting macro-stability effects are indirect.

Table 4: Descriptive 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
L.Policy Uncertainty	0.292	0.202	0.000	1.343
Economic growth	2166.351	2196.429	255.078	10956.945
Inflation	6.012	5.692	-3.233	33.251
Urbanisation	41.000	16.681	10.915	74.261
Human capital	0.821	0.342	0.275	1.493

Table 5: Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Innovation	1.000							
(2) Digital economy	0.329	1.000						
(3) Financial development	0.257	0.695	1.000					
(4) Policy Uncertainty	0.224	0.388	0.445	1.000				
(5) Economic growth	0.266	0.861	0.844	0.478	1.000			
(6) Inflation	-0.042	-0.083	-0.001	0.033	-0.015	1.000		
(7) Urbanisation	0.220	0.712	0.444	0.309	0.726	-0.177	1.000	
(8) Human capital	0.048	0.671	0.663	0.367	0.825	-0.069	0.599	1.000

Table 6: Direct and interactive effects

	(1) Baseline (DE only)	(2) DE+FD	(3) +Lagged Policy Uncertainty (PU)	(4) DE+ Controls	(5) FD+ Controls	(6) Policy Uncertainty Controls	(7) DE+FD +Controls	(8) DE+FD +PU+ Controls	(9) +DE×FD Interaction	(10) +DE×PU Interaction	(11) +FD×PU Interaction	(12) Full Model (Three-way Interaction DE×FD×PU)
L.innovation	0.444***	0.337***	0.315***	0.359***	0.473***	0.429***	0.354***	0.327***	0.294***	0.469***	0.401***	0.288*
	(0.111)	(0.069)	(0.070)	(0.060)	(0.073)	(0.069)	(0.061)	(0.086)	(0.073)	(0.060)	(0.089)	(0.149)
Digital economy (DE)	0.728***			1.010***			1.070***	0.854***	0.667*	-0.838**		0.094
	(0.232)			(0.314)			(0.326)	(0.248)	(0.371)	(0.291)		(0.455)
Financial development (FD)		8.748*			3.374		3.570*	6.482*	2.065		8.933	4.502*
		(4.411)			(4.465)		(2.004)	(3.206)	(2.202)		(9.148)	(2.140)
L.policy uncertainty (PU)			2.393			-0.349		1.090*		1.245	-3.357	1.924
			(2.012)			(1.280)		(0.517)		(0.867)	(2.920)	(1.419)
DE×FD									1.815**			4.653**
									(0.803)			(1.844)
DE×PU									-1.476***			2.136*
									(0.344)			(1.149)
FD×PU										8.167		7.190
										(7.675)		(6.520)
DE×FD×PU												-8.155**
												(3.605)
Net effect w.r.t DE									1.086***	1.251***	11.229	1.201***
Net effect w.r.t FD												6.856***
Net effect w.r.t DEFD												1.201***
												6.856**
Net effect w.r.t DEFD												2.272
Inflation				-0.028	0.104**	0.114**	-0.036	-0.037	-0.035	-0.084	0.128*	-0.035
				(0.045)	(0.050)	(0.049)	(0.046)	(0.055)	(0.051)	(0.051)	(0.073)	(0.056)
Economic growth				-0.000	0.000	-0.000	-0.000	-0.001**	-0.000	0.005***	-0.001*	-0.001**
				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Urbanisation				0.037	0.031	0.054*	0.036	0.102**	0.067**	0.093***	0.103**	0.071**
				(0.024)	(0.023)	(0.028)	(0.024)	(0.038)	(0.029)	(0.032)	(0.044)	(0.032)
Human capital				-3.946***	0.926	1.732	-4.300***	-3.381***	-4.122**	-31.560***	3.284	-3.506**
				(1.267)	(2.094)	(2.179)	(1.393)	(0.752)	(1.449)	(3.514)	(3.228)	(1.317)
Country/time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes Yes	Yes	Yes	Yes	
Observations	192	290	280	138	221	211	138	128	138	128	211	128
No. of instruments	13	13	13	17	17	17	18	18	18	20	19	18
Number of countries	29	29	29	29	29	29	29	29	29	29	29	29
AR(1)	0.003	0.000	0.000	0.018	0.001	0.001	0.020	0.012	0.019	0.012	0.002	0.030
AR(2)	0.488	0.502	0.609	0.919	0.221	0.247	0.935	0.968	1.000	0.768	0.267	0.831
Hansen	0.083	0.048	0.111	0.222	0.081	0.107	0.224	0.163	0.177	0.490	0.136	0.237

Note: All models include time and country fixed effects. Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.2 Baseline Estimates

Table 6 presents the results from the baseline and extended dynamic system GMM estimations for 29 African economies over 2011–2023. All model specifications meet the standard diagnostic requirements. Specifically, the Arellano-Bond test for first-order serial correlation yields p-values below 0.05, indicating the presence of AR(1), while the test for second-order serial correlation produces p-values above 0.10, suggesting the absence of AR(2) and thus no misspecification due to higher-order autocorrelation. The Hansen J-test produces p-values ranging from 0.08 to 0.49, supporting the validity of the instruments used. Additionally, the number of instruments, ranging from 13 to 20, remains well below the number of cross-sectional units (29 countries), mitigating the risk of instrument overfitting.

The lagged dependent variable (L.INNOV) is consistently positive and statistically significant across all specifications, with coefficients ranging from 0.288 to 0.473. This indicates a high degree of persistence in innovation outcomes over time, consistent with cumulative learning and knowledge-spillover effects (Aghion & Howitt, 1992). It underscores path dependence in innovation: countries with existing innovation capacity are more likely to sustain it. However, this persistence can be either virtuous or vicious. In environments of low uncertainty, cumulative innovation learning accelerates; under uncertainty, innovation stagnates due to repeated disruptions.

In the baseline specification (Column 1), the digital-economy index (DE) exhibits a strong and statistically significant positive effect on innovation ($\beta = 0.728$, p < 0.01). Given a standard deviation of 2.15 in the digital-economy index, this implies that a one-standard-deviation improvement in digitalisation raises the innovation score by roughly 1.57 points, equivalent to 8.4 percent of the sample mean (18.7). This magnitude demonstrates that digitalisation has meaningful economic as well as statistical significance for innovation outcomes across African economies.

When financial development (FD) is added in Column 2, its coefficient remains positive ($\beta = 8.748, p < 0.10$). With an observed standard deviation of 0.13 for FD, a one-standard-deviation increase in financial development corresponds to an innovation gain of approximately 1.14 points, or 6.1 percent of the mean innovation score. This finding aligns with theoretical expectations that well-functioning financial systems promote innovation by providing liquidity, reducing information asymmetry, and facilitating long-term investment (Levine, 2005; Nath et al., 2021; Atsu & Adams, 2023).

The combined interpretation of the baseline models therefore indicates that improvements in both digitalisation and financial depth yield economically meaningful innovation dividends. Digital expansion improves information flow and entrepreneurialexperimentation, whereas financial deepening mobilises savings toward productive technological ventures. Their effects are complementary and quantitatively significant, not merely statistically detectable.

Control variables behave as expected. Urbanisation maintains a positive and significant relationship with innovation ($\beta \approx 0.04$ to 0.10), suggesting that a 10-percentage-point rise in urban population share is associated with roughly a 0.4-to-1.0-point higher innovation score. Inflation and economic growth exhibit small or weakly significant coefficients, implying that short-term macroeconomic fluctuations exert limited influence relative to structural and institutional drivers. Collectively, these results highlight that sustained innovation performance in African economies is driven primarily by digital and financial system development within stable macro-policy frameworks, rather than by cyclical growth dynamics.

4.3 Interaction between Digital Economy and Financial Development

When the interaction term $DE \times FD$ is introduced (Column 9), its coefficient is positive and statistically significant ($\beta = 1.815, p < 0.05$), confirming a synergistic innovation dividend between the digital and financial sectors. Using the sample standard deviations for digitalisation (SD(DE) = 2.15) and financial development (SD(FD) = 0.13), the cross-partial effect implies that a one-standard-deviation simultaneous improvement in both variables raises innovation scores by approximately 0.51 points, or 2.7 percent of the sample mean (18.7). In economic terms, economies that deepen their financial systems alongside digital expansion gain almost three additional percentage points in innovation performance relative to comparable economies that progress in only one dimension. This complementarity reflects how digitalisation enhances information efficiency and market reach, while financial deepening channels capital toward innovation-intensive enterprises.

When the interaction term is re-estimated under a broader specification including all controls (Column 12), the coefficient on DE×FDremains positive and statistically significant ($\beta =$

$4.653, p < 0.05)$. The magnitude increases more than twofold relative to Column 9, implying that, after accounting for macroeconomic heterogeneity, a joint one-standard-deviation rise in both DE and FD elevates innovation by roughly 1.30 points ($\approx$ 7 percent of the mean). This reinforces the conclusion that digital and financial developments are mutually reinforcing pillars of innovation, consistent with Schumpeterian and finance-growth theory predictions.

Our finding that the interaction between digital economy development and financial depth significantly enhances innovation accords with a growing body of evidence. For instance, Atsu (2023) shows that financial development raises innovation by improving the information environment and reducing risk. Another recent study on digital finance finds that the digital economy's innovation returns are larger in contexts where firms face fewer financing constraints (Li et al., 2025). In addition, the interplay between technology, financial development and institutional quality is highlighted by Yingying et al. (2025), who demonstrate that technological innovations such as AI yield stronger financial and innovation outcomes where institutional capacity is high. Finally, empirical work on green innovation in China (Chen et al., 2025) supports the notion that digitalisation's contribution to innovation is conditional on supporting financial systems. Overall, digital technologies improve financial efficiency, while developed financial systems furnish the necessary capital to support innovation activities.

4.4 Role of Policy Uncertainty

The inclusion of lagged policy uncertainty (PU) in the model, as shown in Column (6), yields a negative coefficient ($\beta = -0.349$), although its statistical significance varies across specifications. Such variability may reflect differences in the temporal transmission of policy effects or in the structural characteristics of national policy environments. More stable patterns, however, emerge when examining the interaction terms involving policy uncertainty.

The interaction between the digital economy and policy uncertainty ($DE \times PU$) is negative and statistically significant ($\beta = \check{}1.476, p < 0.01$), indicating that elevated levels of policy uncertainty attenuate the positive influence of digitalisation on innovation outcomes. By contrast, the interaction between financial development and policy uncertainty (FD × PU) is positive yet statisticallyinsignificant, suggesting that financial systems in many African economies may remain structurally constrained, thereby limiting their responsiveness to short-term variations in the policy environment. Collectively, these findings underscore the moderating role of policy instability in shaping the relationship between institutional and technological factors and innovation performance, highlighting that uncertainty in the policy domain can undermine the developmental gains derived from digital and financial advancements.

4.5 Triple Interaction: Policy Uncertainty, Digital Economy, and Financial Development

To quantify how policy uncertainty alters innovation returns, we compute marginal effects conditional on PU levels. In Column (12), a triple interaction term encompassing the digital economy, financial development, and policy uncertainty ($DE \times FD \times PU$) is introduced. The coefficient associated with this term is negative and statistically significant ($\beta = \check{}8.155, p < 0.05$), indicating that heightened policy uncertainty substantially weakens the joint influence of digitalisation and financial development on innovation performance. This finding suggests that the potential complementarities between digital and financial advancement are highly sensitive to the stability of the policy environment, with uncertainty diminishing their capacity to jointly foster innovative activity. Our finding aligns with emerging evidence that uncertain or volatile policy environments can suppress technological advancement by amplifying financing constraints and investment risk (Zhang et al., 2022; Marino-Romero & Folgado-Fernández, 2024). It also reinforces the view that institutional and policy stability are critical for enabling the synergistic effects of financial and digital transformation in developing economies (Edo, 2025).

Marginal effects, calculated using the delta method, offer additional insights into these conditional relationships. The marginal effect of the digital economy on innovation conditional on the levels of financial development and policy uncertainty is positive and significant (1.201, p = 0.002). Similarly, the marginal effect of financial development, conditional on digitalisation and policy uncertainty, is also positive and statistically significant (6.856, p = 0.015). The joint marginal effect of the digital economy and financial development, conditional on policy uncertainty, is estimated at 2.272. Taken together, these results highlight a form of conditional complementarity, wherein the positive interaction between digital and financial systems in promoting innovation is contingent upon a stable policy environment. This conclusion is consistent with recent cross-country evidence showing that economic policy uncertainty constrains innovation and investment in both developed and emerging economies (Farooq et al., 2024; Zhang et al., 2022). In the African context, where institutional and regulatory volatility remain salient, these findings underscore the pivotal role of policy coherence and stability in realising the full developmental benefits of digital and financial integration.

5 Discussion and Conclusion

The empirical results analysis demonstrate that innovation performance in African economies is shaped jointly by the expansion of the digital economy and financial development, but that this relationship is sensitive to the broader policy environment. The analysis provides consistent evidence that both digitalisation and finance independently foster innovation, while their interaction amplifies this effect. However, this synergy weakens under conditions of heightened policy uncertainty.

The positive and statistically significant interaction between the digital economy and financial development suggests that these two systems reinforce one another in enhancing innovation outcomes. Digital technologies improve information access, lower transaction costs, and expand the reach of financial services, while well-developed financial systems provide the liquidity, risk management, and capital allocation mechanisms necessary to support innovative activity.

This complementarity accords with established theoretical perspectives linking technological progress and financialintermediation to productivity and growth (Schumpeter, 1983; Aghion & Howitt, 1992; Levine, 2005). It reflects the idea that innovation thrives where information networks and capital markets evolve together, enabling entrepreneurs and firms to convert digital capabilities into new products, services, and processes. In practical terms, the findings underscore the importance of balanced progress digital expansion without parallel improvements in financial access may yield limited innovation payoffs, and vice versa.

Yet, these gains are highly fragile to policy uncertainty. The results reveal that policy uncertainty has a negative and statistically significant moderating effect on the relationship between digitalisation, finance, and innovation. The triple interaction (DE x FD x PU) demonstrates that uncertainty substantially erodes the digital–finance synergy. When macroeconomic, fiscal, or regulatory policies are unpredictable, firms and investors face higher planning costs and risk premiums, leading to delays or cancellations of innovation-related investments. This finding is consistent with theoretical and empirical studies showing that uncertainty raises the value of waiting and discourages irreversible investment (Bloom, 2009; Gulen & Ion, 2016). In such contexts, even strong digital infrastructure and accessible finance may not translate into innovation because firms adopt a cautious stance toward new technologies or market expansion. Policy uncertainty thus operates as a friction that weakens both the direct and interactive effects of digital and financial development on innovation.

Furthermore, the negative role of policy uncertainty points to the institutional foundations of innovation. Innovation outcomes depend not only on the availability of technology and finance but also on the credibility and predictability of the policy environment in which firms and investors operate. Frequent changes in fiscal rules, monetary policy direction, or regulatory regimes disrupt the expectations that underpin long-term planning and collaboration between public and private actors. In other words, when fiscal or monetary authorities behave unpredictably, the innovation ecosystem faces coordination failures banks ration credit, firms hoard liquidity, and digital entrepreneurs defer scaling decisions.

Moreover, the insignificant or weak coefficients on inflation and short-term growth confirm that innovation in Africa is structurally rather than cyclically determined. Macroeconomic stability per se is not sufficient; what matters is predictability. A stable but opaque policy regime can be as damaging as volatility. Hence, innovation policy should be viewed not merely as industrial or digital policy, but as an extension of macroeconomic governance.

These insights align with the broader literature on institutional economics, which emphasises that credible governance and rule-based policymaking reduce uncertainty, lower transaction costs, and create an environment conducive to investment and technological upgrading (North, 1990; Rodrik, 2000). The findings, therefore, highlight that enhancing innovation requires not only digital and financial infrastructure but also stronger institutional capacity to sustain predictable and transparent policy frameworks.

Taken together, the results reframe Africa's innovation challenge from a narrow focus on technological adoption to a broader focus on systemic coherence between technology, finance, and policy. The results illustrate that innovation in Africa emerges from the interaction of three interdependent systems: technological capability, financial intermediation, and policy stability. The digital and financial systems act as immediate enablers of innovation, while policy stability determines the extent to which these enablers can operate effectively. Sustained progress in innovation, therefore, depends on a coordinated approach that integrates investments in technology and finance with consistent and credible policy governance. The evidence implies that investment in broadband, fintech, or human capital will yield sub-optimal outcomes without a stable macro-policy anchor.

In other words, the results underscore the need for macroeconomic and regulatory stability as a precondition for sustained innovation. Governments should institutionalise transparent rulemaking processes, predictable fiscal regimes, and consistent digital-finance policies. Stable expectations reduce the risk premium associated with long-term innovation investments, allowing firms to convert digital capacity into productive outcomes

This insight bears significance for regional initiatives such as the African Continental Free Trade Area (AfCFTA) and the African Union's Agenda 2063. Both envisage a continent-wide digital and financialintegration, yet their success depends on reducing cross-border regulatory volatility. Harmonising digital-finance rules, institutionalising fiscal responsibility laws, and strengthening data-governance regimes can collectively lower uncertainty and enhance the translation of digital progress into innovation.

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