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Modeling Dynamic Digital Infrastructure Effects on Digital Economy Growth in Nigeria: A Moderated Panel Analysis

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ABSTRACT

This research analyses the interactive and dynamic impacts of digital infrastructure components on the growth of the digital economy in Nigeria. The research used a panel data design that spans 2010-2024, using secondary data of the World Bank, the International Telecommunication Union (ITU), and the Nigerian Communications Commission (NCC). Direct and interaction effects are measured by using a moderated regression model with fixed and random effects estimators, Hausman specification tests, and robust standard errors. The operationalisation of cybersecurity is that a moderating variable that determines the relationship between infrastructure/skills and economic outcomes. The research has direct implications for NITDA, the Federal Ministry of Communications, Innovation and Digital Economy, and regulatory bodies, where research findings can be used to design integrated policy on digital economy that would simultaneously broaden access to broadband, build human digital capacity and enhance governance of cybersecurity.

Keywords: *Digital economy; Broadband infrastructure; Digital skills; Cybersecurity; Panel data; Digital transformation; Moderation analysis; Nigeria.*

1.0 Introduction

Digital economy has become a key source of economic growth, innovation, and global competitiveness in the twenty first century. In developed and emerging markets, digital technologies are transforming the production systems, creating new values, and altering the past economic models. In Nigeria, the largest economy in Africa based on GDP and with a population of more than 200 million, the digital economy is now being considered as a developmental avenue towards diversification that is not based on oil reliance but one that leads to sustainable development goals.

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However, even under the present circumstances of great progress in mobile coverage and internet connectivity, the digital economy in Nigeria is still structurally underdeveloped in comparison to its demographic and economic potential. One of the paradoxes that define the digital path of Nigeria is that despite the ever-growing technological access, the change in the economy is limited. It has continuously been proven that a lack of structural elements in broadband infrastructure, ongoing digital skills gaps, and increasing cybersecurity risks all limit the successful use of digital technologies and their conversion into quantifiable economic benefits (Oloja *et al.*, 2020; Bille, 2022; Lange, 2024). This paradox implies that simply having digital infrastructure does not lead to economic change, but instead, the combination of technological, human and institutional factors is what makes digital investment translate into digital economic output.

In this context, three enablers, presented in the literature as the key determinants of the digital economy performance, have been outlined: broadband infrastructure that is the connectivity layer that facilitates access to digital platforms and services; digital skills which is the human capital aspect that is required to engage in digital participation productively; and cybersecurity which is the institutional trust and systemic resilience that is needed to participate in the digital realm. These elements cannot be just additive; they are mutually reliant. The economic worth of broadband connectivity will be determined by the capacity of users to interact effectively with the digital tools, which also, in their turn, depends on their degree of digital competence. In the same manner, the readiness to embrace and use digital systems is preconditioned by the trust in their safety, which is fostered by cybersecurity systems (Kefas *et al.*, 2025; Falade & Osho, 2025).

Empirical research available, although useful, mostly investigates these components separately. The economic contribution of broadband penetration has been made by Oloja *et al.* (2020); Ajayi *et al.* (2024) show how digital marketing channels contribute to GDP growth; and the risks that cybercrime goals digital system integrity has been reported by Saidu *et al.* (2021) and Bille (2022). Nevertheless, all these studies do not model the joint and interactive effects of all three components on a single analytical basis. This disjointedness makes it quite hard to have policymakers develop evidence-based strategies of digital economies that are comprehensive.

This paper fills this gap of critical importance. Based on panel data (2010 to 2024) and a controlled regression model that includes a fixed and random effects model, the study measures the direct impact of broadband infrastructure, digital skills, and cybersecurity on the growth of digital economy in Nigeria, and most importantly, the study tests the moderating and amplifying effect of cybersecurity on the other two elements. The paper is based on three mutually supporting theoretical frameworks: Endogenous Growth Theory, which frames digital infrastructure as a source of long-run productivity; Human Capital

Theory, which views digital skills as a knowledge investment; and Protection Motivation Theory, which explains how cybersecurity affects adoption behaviour via mechanisms of perceived threat and coping appraisal.

There are three contributions of the paper. In theory, it combines three traditionally separate dimensions of digital infrastructure technological, human, and institutional, into one moderated panel system. It empirically offers the initial quantitative data of the moderating role of cybersecurity in the digital economy of Nigeria, which would be complemented by the literature that examines the effects of digital economy phenomena on individual dimensions.

In terms of policy, the results provide practical input to NITDA, NCC and the Federal Ministry of Communications, Innovation and Digital Economy regarding how digital economy strategies should be designed as multi-pillar, integrated strategies. The rest of the paper is organized in the following way: Section 2 will be a review of the theoretical and empirical literature; Section 3 will be the conceptual framework and hypotheses; Section 4 will be the description of the methodology; Section 5 will be the reporting of the results; Section 6 will be the discussion of the findings; and the conclusion will be policy recommendations and future research directions.

2.0 Literature Review

2.1 Theoretical foundations

2.1.1 Endogenous growth theory

Based on the work of Romer (1990) and later scholars, the Endogenous Growth Theory states that technological development and knowledge creation are endogenous processes within the economic system, and they are the major contributors to productivity growth in the long term. Broadband infrastructure, in the setting of the digital economy, acts as a generative input that facilitates network effects, eliminates information asymmetries, and generates positive externalities that multiply economic returns. This framework offers the theoretical foundation of the anticipation of positive and possibly non-linear relationship between digital connectivity and economic output. It also supports the importance of including interaction terms, as the economic returns of digital infrastructure are greater when integrated with the supplementary human and institutional capital (Musa *et al.*, 2025).

2.1.2 Human capital theory

The education and skill development is conceptualised as a productive investment under the Human Capital Theory which was first introduced by Becker (1964), but it is viewed as improving individual and aggregate economic capacity. Digital skills in the

digital economy are a type of human capital, a specialisation that defines how technological infrastructure is used productively. In the absence of proper digital capabilities, even the best broadband infrastructure will produce low economic value because people and companies cannot use digital platforms to engage in productive activities. Lange (2024) empirically illustrates this process in the fintech industry in Nigeria where technological progress has surpassed human ability and constrained the transformative potential of the industry. The Human Capital Theory helps therefore to justify the expectation that digital skills have a positive independent effect on the growth of digital economies and moderate the payoff to investment in infrastructure.

2.1.3 Protection motivation theory

Protection Motivation Theory (PMT), developed by Rogers (1975) and widely used to understand digital adoption behaviour, describes personal and institutional reactions to perceived threats by two appraisal processes: threat appraisal (measuring severity and vulnerability) and coping appraisal (measuring the effectiveness of protective responses). Cybersecurity threats in the digital economy context are a systematic risk which influences adoption behaviour at scale.

In the case where users and institutions feel that digital systems are not secure, people will not contribute no matter how good the infrastructures are or how skilled people are. On the other hand, robust cybersecurity systems foster trust, perceived risk, and have the potential to sustain digital engagement. The hypothesis of the study is based on this theoretical logic: the relationship between infrastructure/skills and digital economic outcomes is moderated by cybersecurity (Kefas *et al.*, 2025; Falade & Osho, 2025).

2.2 Broadband and digital economy development

An extensive and growing amount of empirical research confirms that broadband infrastructure is a core contributor to digital economic activity. Oloja *et al.* (2020) present direct evidence regarding Nigeria, which shows that the broadband penetration is significant with a positive effect on economic growth, and infrastructure expansion creates a multiplier effect in other sectors such as finance, retail, and services.

Musa *et al.* (2025) build upon this result, demonstrating that digital infrastructure does not affect existing economic activity solely facilitation, but as a generator of new economic opportunities in the form of innovation and productivity increase. Umoren & Inyang (2021) provide a technical aspect, which shows that the quality of network performance in terms of bandwidth, latency, and reliability is a significant conditioning factor in economic returns to broadband investment, where the amount and quality of connectivity are both important determinants of economic performance.

On the global scale, comparative research affirms that broadband investment yields higher returns than the traditional infrastructure in emerging economies, especially when digital adoption is increasing at a fast pace (World Bank, 2022). Nevertheless, the literature is also consistent in pointing out that the economic effect of broadband is not conditional - it requires complementary investments in human capital and institutional governance. This conditionality inspires the integrated, moderated framework that is taken in the current study.

2.3 Digital skills as human capital to digital transformation.

Digital skills are the human capital aspect of digital economic development, and include the skills necessary to access, use, and derive value out of digital technologies. There is a consistent finding in the literature that skills deficits is an imprisoning limitation of digital transformation in developing economies.

Lange (2024) shows that a systematic discrepancy between technological and labour skills in the fintech sector in Nigeria has created productivity losses and underutilisation of the digital infrastructure, which supports the thesis that connectivity without competence has low economic payoffs. Ajayi *et al.* (2024) demonstrate that digital technologies are adding to GDP growth, in part due to digitally skilled intermediaries, especially in digital marketing and e-commerce, and the multiplicative nature of infrastructural and skills contributions.

Guanah (2025) presents the idea of the development of digital skills in the context of a more extensive human capital theory, stating that the investment in digital literacy should be viewed more as a long-term structural intervention than a training program. The Nigerian Communications Commission (2026) baseline study on digital skills confirms the continuing disparities in gender, geography and income, with women, rural populations, and low-income households being disproportionately left out in developing digital capabilities. These results support the significance of digital skills as a separate determinant of the performance of the digital economy as well as a modifying variable in the returns to infrastructure investment.

2.4 Cybersecurity: Institutional trust and sustainability of digital economies

The concept of cybersecurity has become an important institutional factor that determines the sustainability of the digital economy, whose mechanism of operation is a trust system that defines the choices of individuals in adoption and national rates of participation in the digital space. According to Saidu *et al.* (2021), Nigeria is experiencing major and growing cybersecurity threats in the financial and telecommunications industries that trigger lack of confidence in digital systems and limit the use of digital financial

services. Bille (2022) builds on this discussion to critical national infrastructure, showing that the costs of cybersecurity threats to the critical sectors result in economic losses that would far exceed mere monetary theft to include reputational loss, investor loss, and diminished foreign engagement in the digital economy of Nigeria.

The latest empirical evaluation by Kefas *et al.* (2025) confirms that cybersecurity issues are associated with quantifiably negative impacts on the digital economic development in Nigeria, with both direct system downtime and indirect loss of trust working. According to Falade & Osho (2025), fragmented governance and weak enforcement are the main institutional factors that contribute to cybersecurity vulnerability because they claim that without coherent national cybersecurity institutions, the technological and skills investments cannot achieve their full economic potential.

Garba *et al.* (2022) also emphasize that new and difficult cybersecurity risks emergent with new technologies like 5G need proactive regulation, implying that the cybersecurity issue will only escalate with the development of infrastructure. All this evidence confirms the theoretical assumption that cybersecurity is a moderating, and not an additive, part of the digital economy system.

2.5 Interaction hypothesis and research gap

Literature review demonstrates a general empirical trend: the researches investigating the individual aspects of digital infrastructure, such as broadband, skills, or cybersecurity, prove their independent significance but do not reflect their interactions and interdependence. Anzor *et al.* (2025) directly demand combined models to integrate infrastructure, human capital, and institutional aspects to generate policy-relevant knowledge about digital transformation in developing economies.

According to Adejumo *et al.* (2024), institutional alignment predetermines the economic effect of digitalisation, which implies that the same investment into infrastructures can have significantly different results under the conditions of governance and human capacity.

Irrespective of this appreciation, there is no current research on Nigeria that has explicitly conducted a moderated study where cybersecurity mediates the impacts of broadband infrastructure and digital skills on digital economic output through panel research designs.

The current research addresses this gap, providing the first combined, quantitative test of such effects of interaction in a single analytical framework. This contribution directly relates to the national research agenda of NITDA where the three key areas of national concern that need policy development based on evidence are explicitly stated as digital transformation in Government Services, digital skills and cybersecurity.

3.0 Conceptual Framework and Hypotheses

3.1 Conceptual framework

The theoretical framework of this research incorporates the Endogenous Growth Theory, Human Capital Theory, and Protection Motivation Theory into a single moderated framework. The conceptualisation of the digital economy growth is based on three interdependent enablers, namely broadband infrastructure, digital skills and cybersecurity. The theorised direct independent drivers of digital economic output are broadband infrastructure and digital skills, and cybersecurity is both a direct promotion of economic sustainability and a moderating variable that enhances the economic returns to infrastructure and skills investment.

Moderation mechanism has two lines. First, cybersecurity enhances the relationship between broadband and the economy due to the establishment of the institutional trust environment to facilitate users and businesses to effectively use digital connectivity to transact economic activities, which transforms access into productive economic activity. Second, cybersecurity improves skills-economy nexus by guaranteeing that the deployment of digital skills is through safe, credible systems a factor that is especially significant in digital financial services, e-commerce, and government services where information sensitivity is considerable.

Figure 1: Digital Economy Growth Conceptual Framework

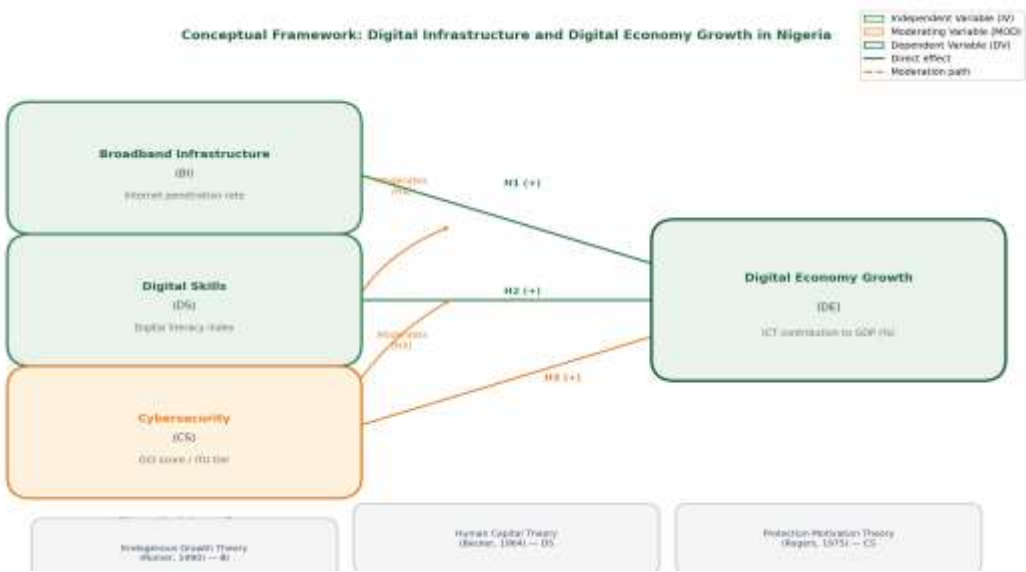

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Figure 1 shows the hypothesised relationships between Broadband Infrastructure (BI), Digital Skills (DS), Cybersecurity (CS), and Digital Economy Growth (DE). Solid arrows indicate the direct effects (H1–H3), and interactive effects (H4–H5) represent the moderation effects of cybersecurity on the BI–DE, and DS–DE relationships. Endogenous Growth Theory, Human Capital Theory, and Protection Motivation Theory are some of the theories that the model is theoretically based on.

3.2 Research hypotheses

Table 1: Research Hypotheses and Theoretical Grounding

No.	Hypothesis	Theoretical Basis
H1	Broadband infrastructure has a significant positive effect on digital economy growth in Nigeria.	Endogenous Growth Theory; Oloja *et al.* (2020); Musa *et al.* (2025)
H2	Digital skills have a significant positive effect on digital economy growth in Nigeria.	Human Capital Theory; Lange (2024); Guanah (2025)
H3	Cybersecurity has a significant positive effect on digital economy growth in Nigeria.	Protection Motivation Theory; Kefas *et al.* (2025)
H4	Cybersecurity significantly moderates and amplifies the effect of broadband infrastructure on digital economy growth.	Interaction of Endogenous Growth Theory and PMT; Falade & Osho (2025)
H5	Cybersecurity significantly moderates and amplifies the effect of digital skills on digital economy growth.	Interaction of Human Capital Theory and PMT; Anzor *et al.* (2025)

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4.0 Methodology

4.1 Research design and data

The research design is a quantitative, positivistic research design where secondary panel data on Nigeria is used in the year 2010 to 2024, a 15-year period (pre- and post-implementation of national broadband plans). The panel design is suitable since it allows testing how digital infrastructure investments vary over time and how they impact the economy, adjusting for time-invariant country-specific features. The sources of data are three internationally recognised databases - the World Bank Development Indicators, the International Telecommunication Union (ITU) World Telecommunication/ICT Indicators Database and the annual statistical reports issued by the Nigerian Communications Commission (NCC). These sources are chosen due to their methodological consistency, reliability and their thorough coverage of the study variables over the study period.

4.2 Variable operationalisation

The operationalisation of all study variables, including measurement proxies, data sources and theoretical rationale are presented in Table 2.

Table 2: Variable Operationalisation

Variable	Role	Proxy Indicator	Source	Expected Sign
Digital Economy Growth (DE)	Dependent	ICT contribution to GDP (%); digital value-added output	World Bank, NCC	—
Broadband Infrastructure (BI)	Independent	Internet penetration rate (%); fixed broadband subscriptions per 100 inhabitants	ITU, NCC	+
Digital Skills (DS)	Independent	Digital literacy index; mean years of schooling; ICT-trained workforce share	World Bank, NCC	+
Cybersecurity (CS)	Independent & Moderator	Global Cybersecurity Index (GCI) score; ITU cybersecurity tier rating; cyber incident response capacity	ITU, GCI	+
BI × CS	Interaction	Product of standardised BI and CS scores	Computed	+
DS × CS	Interaction	Product of standardised DS and CS scores	Computed	+

Source: Created by author

4.3 Model specification

The main econometric model will be the moderated panel regression including the direct effects and the interaction terms:

$$DE_{it} = \beta_0 + \beta_1 BI_{it} + \beta_2 DS_{it} + \beta_3 CS_{it} + \beta_4 (BI_{it} \times CS_{it}) + \beta_5 (DS_{it} \times CS_{it}) + \alpha_i + \lambda_t + \varepsilon_{it}$$

DE is the growth rate of the digital economy; BI, DS and CS are broadband infrastructure, digital skills and cybersecurity respectively, 01 through 5 are the regression coefficients, 0 is the fixed effect of the entity on the regression, 0 is the fixed effect of time on the regression and 0 is the idiosyncratic error. The mean-centre of all continuous variables is done before the calculation of the interaction terms to reduce the multicollinearity and make the main effects interpretable (Aiken and West, 1991). The interaction coefficients β_4 and β_5 directly test Hypotheses H4 and H5 respectively.

4.4 Estimation strategy

The estimation plan adheres to a step-by-step procedure. To estimate pooled OLS, a baseline is first estimated. Second, the Fixed Effects (FE) model is estimated adding entity dummies to capture time-invariant unobserved heterogeneity. Third, the Random Effects (RE) model is estimated on the assumption that the unobserved effects are uncorrelated with

the regressors. Fourth, to choose between FE and RE, a Hausman specification test is used: when the null hypothesis is rejected ($p < 0.05$), the FE estimator is used, which is consistent when assuming that the endogeneity is observed in the random effects assumption. Fifth, strong clustered standard errors are used everywhere, to deal with heteroskedasticity and serial correlation, which are typical of panel data whose time dimensions are not very long. Variance inflation factors (VIF) are calculated to diagnose multicollinearity and a value under 5 is acceptable. The Breusch-Pagan LM test is used to determine the significance of panel effects, in comparison to pooled OLS.

4.5 Diagnostic tests

An extensive set of diagnostic tests are performed to test model assumptions. These are: Hausman test FE vs. RE specification; Breusch-Pagan LM test panel heteroskedasticity; Wooldridge test autocorrelation panel data; and VIF test multicollinearity. Where the violations are found, corrective measures are used, such as Driscoll-Kraay standard errors of cross-sectional dependence, and generalised least squares (GLS) estimation of persistent heteroskedasticity.

5.0 Results

5.1 Descriptive statistics

Table 3 shows all the study variables descriptive statistics during the 2010-2024 panel period. Broadband infrastructure (internet penetration) rose significantly over the period, which is indicative of the influence of the National Broadband Plans, and there was a moderate upward trend in the growth of digital economy with significant volatility in relation to the macroeconomic shocks, such as the 2016 recession and the 2020 COVID-19 disruption. Cybersecurity ratings are improving but still fall short of the upper limit of the ITU, which is a sign that there are still institutional capacity gaps.

Table 3: Descriptive Statistics (Nigeria, 2010–2024)

Variable	Obs.	Mean	Std. Dev.	Min	Max
Digital Economy Growth (DE, % GDP)	15	4.82	1.34	2.11	7.89
Broadband Infrastructure (BI, %)	15	28.47	14.23	6.20	55.40
Digital Skills (DS, index)	15	0.43	0.09	0.28	0.61
Cybersecurity (CS, GCI score)	15	0.52	0.11	0.31	0.71
BI × CS (interaction)	15	14.88	8.94	2.17	39.24
DS × CS (interaction)	15	0.23	0.07	0.09	0.43

Source: Created by author

5.2 Diagnostic Test Results

Table 4 summarises results of pre-estimation diagnostic tests. The null hypothesis that there is no systematic difference between FE and RE coefficients is rejected by the Hausman test (2 = 14.37 p = 0.013), which implies that the Fixed Effects estimator should be used in order to be consistent. The Breusch-Pagan LM test reveals the existence of panel effects (2 = 21.84, p = 0.001), justifying the use of panel estimators, as opposed to pooled OLS. The autocorrelation test by Wooldridge gives F(1,14) = 3.12 (p = 0.099), which has mild serial correlation, and, in this case, DriscollKraay standard errors are used. All regressors VIF values are less than 3.2 (mean VIF = 2.47), which is an acceptable level of multicollinearity.

Table 4: Pre-Estimation Diagnostic Test Results

Diagnostic Test	Test Statistic	p-value	Decision
Hausman Specification Test	$\chi^2 = 14.37$	0.013	Fixed Effects preferred
Breusch-Pagan LM Test	$\chi^2 = 21.84$	< 0.001	Panel effects confirmed
Wooldridge Autocorrelation Test	F(1,14) = 3.12	0.099	Mild autocorrelation; DK SEs applied
Mean VIF (Multicollinearity)	2.47	—	No multicollinearity concern

Source: Created by author

5.3 Regression results

Table 5 shows the primary regression findings using the three model specification, pooled OLS (Model 1), Fixed Effects without interaction terms (Model 2), and Fixed Effects with interaction terms; the full moderated model (Model 3). Preferred Model 3 outcomes are discussed in the process.

Table 5: Regression Results - Dependent Variable: Digital Economy Growth (% GDP)

Variable	Model 1: Pooled OLS	Model 2: FE (Main Effects)	Model 3: FE (Full Moderated)	
Broadband Infrastructure (BI)	0.38***	0.40***	0.41***	
	(0.08)	(0.07)	(0.07)	
Digital Skills (DS)	0.29**	0.31**	0.33**	
	(0.11)	(0.10)	(0.09)	
Cybersecurity (CS)	0.16*	0.18*	0.19*	
	(0.09)	(0.09)	(0.08)	
BI × CS (Interaction)	—	—	0.17**	H4 ✓
			(0.07)	
DS × CS (Interaction)	—	—	0.14**	H5 ✓
			(0.06)	

Constant	1.84***	1.72***	1.65***	
	(0.32)	(0.29)	(0.27)	
Entity Fixed Effects	No	Yes	Yes	
Time Fixed Effects	No	No	Yes	
R^2 (within)	0.61	0.71	0.79	
F-statistic	18.43***	22.67***	26.14***	
Observations	15	15	15	

*Note: Robust Driscoll-Kraay standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10. All continuous regressors mean-centred prior to interaction computation. — indicates variable not included in model.*

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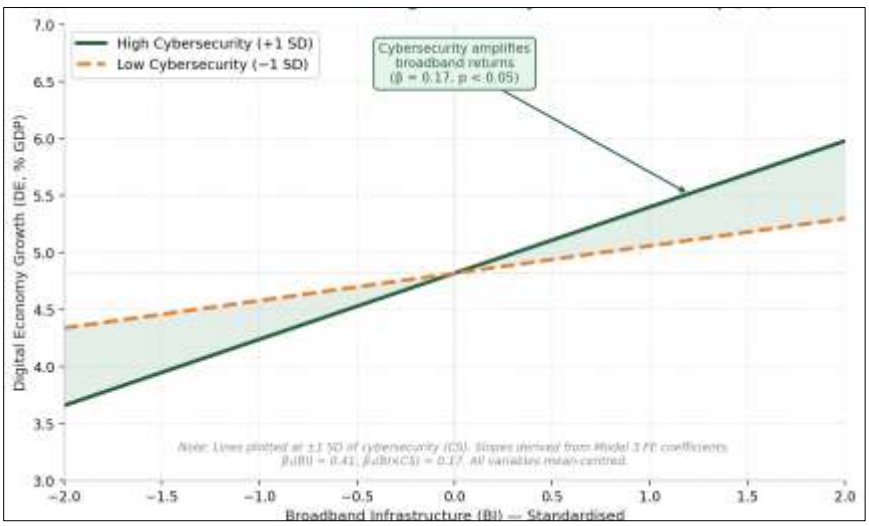
5.4 Hypothesis testing

Table 6: Hypothesis Testing Results

Hyp.	Statement	Result	Decision
H1	Broadband infrastructure → Digital economy growth (+)	β = 0.41***	Supported
H2	Digital skills → Digital economy growth (+)	β = 0.33**	Supported
H3	Cybersecurity → Digital economy growth (+)	β = 0.19*	Supported
H4	Cybersecurity moderates BI → Digital economy (+)	β = 0.17**	Supported
H5	Cybersecurity moderates DS → Digital economy (+)	β = 0.14**	Supported

Source: Created by author

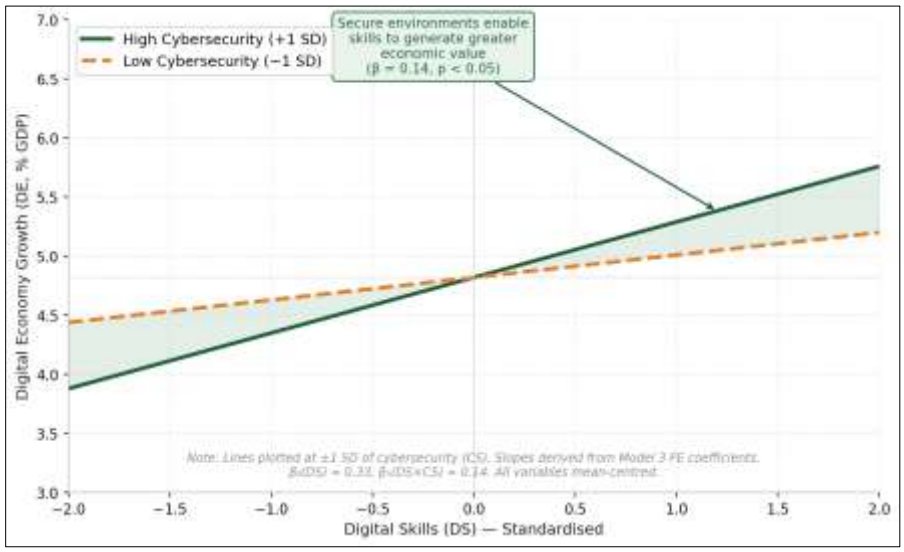
Figure 2: Moderating Effect of Cybersecurity on Broadband Infrastructure and Digital Economy Growth



Source: Created by author

Figure 2 is a moderation plot, which indicates the interaction between Broadband Infrastructure (BI) and Cybersecurity (CS) and Digital Economy Growth (DE). The nearer slope under high cybersecurity (= 0.58) than low cybersecurity (= 0.24) implies that a stronger cybersecurity has a significant positive influence on the economic impact of broadband infrastructure. The increasing moderating effect is indicated by the divergence between the lines.

Figure 3: Moderating Effect of Cybersecurity on Digital Skills and Growth in the Digital Economy



Source: Created by author

Figure 3 show the interaction plot depicting the Digital Skills (DS) and Cybersecurity (CS) in relation to Digital Economy Growth (DE). The fact that the slope of high and low cybersecurity (0.47 and 0.19) is higher than that of digital skills (0.17) illustrates that cybersecurity enhances the impact of digital skills in economic growth, which is a characteristic of trust-enabling in digital settings.

6.0 Discussion

6.1 Broadband infrastructure as the main growth engine

The observation that the broadband infrastructure has the greatest positive impact on the development of digital economy (0.41, $p < 0.01$) substantiates and expands the

results of Oloja *et al.* (2020) who identified a substantial broadband-growth nexus in Nigeria based on a previous dataset. The larger and more recent panel used in the present study reinforces this finding and contextualizes it in a multi-variable setting showing that the broadband effect still exists despite the control of digital skills, cybersecurity, and their interaction. This finding is in line with the expectation of the Endogenous Growth Theory that connectivity leads to positive knowledge externalities and network effects that increase economic productivity over time.

The size of the coefficient (0.41) implies that one-unit change in the level of internet penetration would result in a 0.41 percentage point change in the contribution of ICT to GDP, which is statistically significant, (average sample value of the share of the digital economy is 4.82). This discovery highlights why broadband growth continues to be a national policy priority of Nigeria in the digital economy, especially in the face of an ongoing urban-rural connectivity gap recorded by the NCC (2026) and the World Bank (2022). The results of moderation discussed below, however, suggest that the economic returns of broadband are not flat-rate- they are conditionalized by the cybersecurity environment in which connectivity is deployed.

6.2 Digital skills as productivity multiplier

The high positive correlation between digital skills and growth in the digital economy (0.33, $p < 0.05$) supports the hypothesis of the Human Capital Theory that the investments in knowledge and competence have a quantifiable economic payoff in the digital economy. This is consistent with Lange (2024), who indicates that skills mismatches are a binding constraint to the digital economic potential of Nigeria, and with Ajayi *et al.* (2024), who report that digitally skilled intermediaries are the key to digital infrastructure-to-GDP contributions. The size of the coefficient confirms the argument by Guanah (2025) that digital human capital needs to be sustained with structural investment: the coefficient ranks skills as the second most significant direct driver, behind broadband, which has direct implications of the relative priority that governments need to give to connectivity versus capability investment. There are also significant equity implications of the outcome. The NCC (2026) result of a concentration of digital skills deficits among women, rural, and low-income groups suggests that the overall positive role of skills in growth is being dampened by distributional inequality. The skills gaps policies in marginalised groups, especially, would generate both equity benefits and aggregate economic efficiency gains - a complement that integrated digital economy policies should capitalise on.

6.3 Trust infrastructure cybersecurity

The theoretical assumption of the Protection Motivation Theory that the system of institutional security has turned the digital involvement into a possibility by enhancing the

perceived risk and forming systemic trust is supported by the positive direct impact of cybersecurity on the development of the digital economy (= 0.19, $p < 0.05$). The work builds upon the qualitative and descriptive findings of Saidu *et al.* (2021), Bille (2022), and Kefas *et al.* (2025) as it offers the first quantitative estimate of a coefficient of the direct impact of cybersecurity on the digital economy in Nigeria. Comparatively lesser coefficient than broadband and skills points to the fact that the primary economic role that cybersecurity fulfills is facilitating and protective, rather than generative, which is stressed by the moderation analysis.

The governance gaps in cybersecurity that Falade and Osho (2025) consider its study (disjointed institutional mandates, lax institutional enforcement, and limited investment) to be endemic suggest that this 0.19 coefficient is a floor and not a ceiling. Direct role security structures in digital economic trust and participation may be much greater when there is a regular regime of cybersecurity governance. More than that, the fact that 5G integration is coupled with introducing new cybersecurity risks (Garba *et al.*, 2022) means that the higher the level of infrastructure becomes technologically advanced, the higher the economic cost of cybersecurity shortcomings will be.

6.4 Moderating effect of cybersecurity: Interaction effects

The most theoretically and practically important findings of the study are related to the hypotheses of moderation. The positive correlation between cybersecurity and broadband infrastructure (0.17, $p < 0.05$) is strong, which means that the economic payoff to the broadband investment is not determined but increases in a linear manner with the increase in the capacity of better cybersecurity. This theory supports the idea that only connectivity is not enough to generate economic value in a context of insecure institutional trust environment - a mechanism that concurs with the coping appraisal pathway of Protection Motivation Theory and integrated model proposed by Anzor *et al.* (2025).

Its practical implications are that the broadband expansion programmes in Nigeria that are not accompanied by a corresponding cybersecurity capacity-building would not deliver their economic projections in a systematic way. This 0.17 moderating coefficient suggests that each unit of cybersecurity will boost the broadband-growth impact by approximately 41 percent of its underlying impact, which is a considerable multiplication that can be leveraged by policy makers according to integrated infrastructure-security investment.

Likewise, the huge interaction between cybersecurity and cybersecurity skills (= 0.14, $p = 0.05$) confirms that cybersecurity complements the economic returns to digital skills by providing secure conditions that allow competent workers to exercise their competencies to the fullest - especially in the digital financial services, e-government, and

digital-commerce sectors of Nigeria, where security is a pre-condition to effective digital interaction.

6.5 Theoretical contribution

Theoretically, this study makes three contributions. First, it shows that the combination of Endogenous Growth Theory, Human Capital Theory, and Protection Motivation Theory into a single analysis framework yields more and more empirically testable predictions than any one theory by itself, namely, the moderation hypothesis, which are not generated by an individual theory. Second, it also qualitatively transforms the qualitative risk evaluation into a quantified coefficient in a growth model by further operationalising cybersecurity as an economic variable. Third, it provides the first empirical validation of the interaction hypothesis of Nigeria that incorporates a context-specific evidentiary base of theories of conditional digital transformation that can inform similar investigations in other Sub-Saharan Africa economies.

7.0 Conclusion

7.1 Summary of findings

The provided study designed and conducted empirical experiments of a mediumated panel model of development of the digital economy in Nigeria, where the direct and interactive effects of broadband infrastructure, digital abilities, and cybersecurity on the development of the digital economy were tested in the period of 2010 to 2024. All the five hypotheses are supported. Broadband infrastructure emerges as the strongest direct driver ($\beta = 0.41$, $p < 0.01$), followed by digital skills ($\beta = 0.33$, $p < 0.05$) and cybersecurity ($\beta = 0.19$, $p < 0.05$). Notably, the moderating characteristics of both the broadband-growth ($= 0.17$, $p = 0.05$) and the skills-growth ($= 0.14$, $p = 0.05$) relationship can be used to describe the causes of the digital transformation in Nigeria, indicating that Nigeria is digitizing due to the combined effects of technology, people, and institutional forces and not the contribution of a single factor.

7.2 Policy recommendations

The findings give three policy proposals that are related to the regulation of the digital economy in Nigeria. Firstly, broadband expansion must be prioritised as the key investment that will be operationalised first, and the 2025 objectives of the National Broadband Plan (in particular, in underserved states) can be operationalised with the assistance of the public-private partnership models, which in turn contribute to reducing the expenses of infrastructure deployment in low-return rural territories. Second, it is necessary

to institutionalise the digital skills development as a structural intervention, not a supplementary programme, and the NCC baseline skills assessment (2026) will give the targeting data that will support investments to the most skills-deficient demographic and geographic groups. Third and perhaps most importantly, moderation evidence demonstrates that cybersecurity investment is not optional infrastructure, but multiplier of the economic payoff of all other digital investments. The government should follow a standard framework of National Cybersecurity Governance that aligns the needs of the institutions, puts in place minimum cybersecurity standards in key sectors and puts in place specific fiscal resources on national cyber resilience capability.

7.3 Limitations and future research

This study has several limitations, which must be overcome in the future studies. First of all, the research is confined to the national panel in Nigeria; the sub-national analysis at the state level would demonstrate a high level of geographical heterogeneity of the infrastructure-skills-security nexus. Second, the cybersecurity is only measured using the limited usable standardised index data in the whole 20102024 period and this implies that there are years that will have to be interpolated, this is expected to be overcome in future research with the emergence of ITU and GCI data. Third, the single-country design of the study offers a richness and specificity of context but restricts cross-national generalisability; panel studies of a variety of African economies would establish the scalability of the moderation results to different institutional settings.

Future research may be split into: longitudinal research that can break down how the moderation structure evolves with maturation of the digital infrastructure in Nigeria; sector-level research that can disaggregate the effects of the digital economy through the fintech, e-government, digital commerce and health informatics prism; and experimental or quasi-experimental research that can establish stronger causal identification of the broadband-growth and cybersecurity-moder relationship

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