NAMM Nigerian Association of Macroeconomic Modellers

...Modelling a greater economy

4TH ANNUAL NAMM INTERNATIONAL HYBRID CONFERENCE

Conference Proceedings

CONFERENCE THEME

Policy Innovation for Economic Recovery, Structural Transformation and Digital Macroeconomic Modelling

EDITORS

Emmanuel Agiaye, Oluwafemi S. Abioye, Lucy Nwobi, Abiola Akande and Tubi Theophilus

DATES

26 – 27 November 2025

VENUE

Subomi Conference Centre
University of Ibadan

FORMAT

Hybrid: in person and online

Proceedings of the 4th Annual NAMM International Hybrid Conference

Policy Innovation for Economic Recovery, Structural Transformation and Digital Macroeconomic Modelling

26–27 November 2025 · Subomi Conference Centre, University of Ibadan, Nigeria · Hybrid (in person and online)

Editors: Emmanuel Agiaye, Oluwafemi S. Abioye, Lucy Nwobi, Abiola Akande and Tubi Theophilus

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Conference Programme

Day 1: Wednesday 26 November 2025

Conference Registration, Arrival and Confirmation of Participants

Opening Ceremony

- The Nigerian National Anthem
- Introduction and Welcome of Guests
- NAMM President's Welcome Address by **Professor Philip O. Alege**
- Conference Chair Opening Remarks by **Professor Anthony E Akinlo**
- Goodwill Messages – ADSR, PILAF, NISER, CBN, NBS, UI, AfDB–20min

Keynote Address 1 by Dr. Mohammed M. Tumala, Former Director Statistics Department at the Central Bank of Nigeria (CBN)

- **Topic:** Policy Innovations for Economic Recovery & Digital Macroeconomic Modelling

Presentation of NAMM Model I: Integrating AI with the Small Macroeconometric Model for Real-Time Monetary Policy Simulation in Nigeria by **Prof. Olusanya E. Olubusoye** & **Dr Ephraim Ogbonna**

Presentation of NAMM DSGE Model II: AI Enhanced DSGE Modelling for Policy by **Prof. Philip O. Alege, Dr. A. A. Adegboye, Dr. Queen E. Oye and Dr. Dauda Musa**

Plenary on AI and Digital Macroeconomic Modeling (focused on Impact of AI, LLMs, and new computational methods on forecasting. Exploring advances in digital macroeconomic modelling techniques, including the use of big data, machine learning, and real-time analytics to improve forecasting, scenario analysis, and policy evaluation. And the future of Central Bank modelling and forecasting tools)

Alignment: Digital Macroeconomic Modelling, Economic Recovery.

- Topic: **Artificial Intelligence and New Digital Tools for Forecasting**

Chairman: **Dr. Usman M. Okpanachi,** Director, Statistics Department, CBN

Panelists:

- **Dr. Michael A Adebiyi,** Former Director Research Department CBN
- **Ms. Peace Olubere**, COO, ADSR
- **Dr Aminu Maida**, CEO & Executive Vice Chairman, NCC
- **Prince Adeyemi Adeniran**, Statistician General, NBS
- **Mr. Adeladan Rafiu Olarinre**, Perm.Sec., Fed. Ministry of Communication
- **Mr Tunji Bello,** CEO/Executive Vice Chaiman, FCCPC
- **Mr Felix Okonkwo,** Director Macro, Fed. Min. of Budget & Economic Planning
- **Ms Omolala Oloworanran,** DG, National Pension Commission
- **Mr Moses Okpanachi Usman,** Director of Statistics CBN

Technical Session I:

Macroeconomic Modelling for Policy Formulation in the Digital Age

Session Chairperson: Prof. Adeola Adenikinju

Co-Chair: Dr. Queen-Esther Oye

NAMM-1101025	**Invited Paper Presentation 1:** Cryptocurrency and Fiat Monetary Transmission Dynamics in Nigerian Economy: A Bayesian DSGE Approach	• Nwosu C. Anthony; Marcus S. Nnamdi; Nwaogwugwu C. Sophia
NAMM-1102925	**Invited Paper Presentation 2:** Artificial Intelligence &Sustainable Development in Nigeria: CGE Analysis	• Abiola S. Akande; Aminat Omilania

Parallel / Concurrent Sessions I

Macroeconomic Modelling for Policy Formulation in the Digital Age; Digital Transformation and Economic Recovery; Exchange Rate Volatility and Digital Solutions

Room 1: Digital Transformation and Economic Recovery

Session Chairperson: Prof Olu Ajakaiye**; Co-Chair:** Dr. Queen-Esther Oye

Paper No.	Paper Title	Author(s)
NAMM-1101625	AI-Driven Mobile Money Analytics for Smarter Economic Policy in Nigeria	• Oluwafemi Bisiriyu; Oluwafemi S. Abioye
NAMM-1102225	Innovative Financing and Digital Transformation for Economic Recovery in Sub-Saharan Africa: A Financial Economics Perspective	• Abdullahi Sani
NAMM-1102325	Modelling Digital Finance And Macroeconomic Performance In Nigeria	• Iwasam Egbe; Philip O. Alege
NAMM-1102525	Fintech, Blockchain And Financial Inclusion In Nigeria	• Omilani Aminat
NAMM-1103025	Macroeconomic Effects of the Digitalization of Tax Revenue Collection in Nigeria: A Bottom-Up Approach	• Desmond O. Echeta; Christian C Chima; Amarachukwu C Arinzeh; Francis O Nwaigwe; Ferdinand Nwabueze; Onyewuenyi Kelechi
NAMM-1102025	Economic Policy Uncertainty and Carbon Emission Cycles in Nigeria: A DSGE Perspective	• Musa Dauda; Philip O. Alege
NAMM-1100825	AI-Enhanced Intrusion Prevention Systems For Securing Digital Economies	• Victoria Nkem EMMANUEL
NAMM-1103426	IMPACT OF DIGITAL INFRASTRUCTURE ON THE NIGERIAN ECONOMIC GROWTH	• Dorcas Ayanwola; Philip O. Alege

Room 2: Macroeconomic Modelling for Policy Formulation in the Digital Age, Exchange Rate Volatility and Digital Solutions

Session Chairperson: Prof Christopher U Kalu; **Co-Chair:** Dr. Chinedu Nwosu Anthony

Paper No.	Paper Title	Author(s)
NAMM-1100525	Analysing Macroeconomic Shocks in Selected African Economies Using Panel VAR: A Python-Based Approach	• Dalhatu Bello; Umeokwobi Richard; Adams Joshua; Anih David
NAMM-1100925	Gross Domestic Product and External Debt Stock Nexus in Nigeria, 2000-2023: A Granger Causality Investigation	• Rev.Sr (Dr.) Epiphania U. Eziocha
NAMM-1101325	Policy Coherence for Economic Justice: Assessing Nigeria's Economic Policies Against the SDGs	• Peace U. Oko; Ogochukw Muoneke
NAMM-1101425	Rethinking Financial Inclusion through the Institutional Conversion Gap: A Data-Driven Framework for Digital Macroeconomic Modelling and AI Policy Simulations	• Geoeges Magloire Foaleng Fokam
NAMM-1100225	ASYMMETRIC IMPACT OF EXCHANGE RATE FLUCTUATION AND FOREIGN DIRECT INVESTMENT IN NIGERIA	• Usman J. Muhammed; Alhassan Abdulkareem; Agunbiade Olabode
NAMM-1100325	Crypto-currencies and Stock Market Performance: Evidence from the Nigerian Stock Exchange Market	• Ariyibi Mayowa; Yinusa Olumuyiwa; Obadeyi James
NAMM-1100625	CURRENCY SUBSTITUTION INDEX IN NIGERIA	• Dalhatu Bello; G.U. Ebuh (Dr); L. R. Bala-keffi (Dr); U.M. Okpanachi (Dr); I.B.Ezike(Dr); J.O. Obeta; R.O.Umeokwobi (Dr); D.S. Yusufz; B.A. Umemezia

Day 2: Thursday 27 November 2025

Conference Registration, Arrival and Confirmation of Participants

Keynote Address 2 by Dr. Usman M. Okpanachi, Director, Statistics Department at the Central Bank of Nigeria (CBN)

- **Topic**: The role of Data, Modelling and digital technologies in shaping macroeconomic policy framework in Nigeria

Fiscal Achievements Presentation by Mr. Sampson Ebimaro, Ag Perm. Secretary Federal Ministry of Budget and Economic Planning**.**

- **Topic:** Federal Government 2025 Budget Implementation Performance: Achievements and Challenges

Presentation of NAMM CGE Model III:

by **Mr O.T. Tubi, Mr Abiola Akande** and **Mr Iredele Ogunbayo**

Panel Session on Sub-regional, Regional and Global Macroeconomic Policy Modelling, Coordination and Implementation Efforts.

(Focus: Addressing how macroeconomic models can incorporate the complexities of global shocks and interdependencies to inform policymaking in an interconnected world. Enhancing Macroeconomic Policy Simulation for Climate-Resilient Growth)

Chairperson: Prof. Adeola Adenikinju, President NES & Pioneer President NAMM

Discussants:

- **Prof. Olu Ajakaiye**, Executive Chairman, ACSDCB-Ibadan
- **Dr. Santigie Mohamed Kargbo**, Senior Economist WAMA, Sierra Leone
- **Mr Christian Ebeke**, IMF Nigeria Country Rep
- **Mrs Shonekan Aderinola,** Director of Research CBN
- **Dr Lamin G. Barrow,** Country Director, AfDB
- **Mr Samson Ebimaro**, Ag. Perm Sec, FMoBEP
- **Mrs Lydia Shehu Jafiya,** Perm Sec, Federal Ministry of Finance
- **Dr Tanimu Yakubu,** Director General, Budget Office of the Federation
- **Mr Mathew Verghistools**, World Bank Country Representative

Technical Session II:

Macroeconomic Modelling for Policy Formulation in the Digital Age

Session Chairperson: Prof. Adeola Adenikinju

Co-Chair: Dr. Queen-Esther Oye

.....	**Invited Paper Presentation 3:** Financial Innovation, Financial Market Dynamics and Economic Transformation	• Johnson Chukwu
NAMM-1100725	**Invited Paper Presentation 4:** Assessing policies for promoting food and nutrition security in Nigeria	• Oluwasola E. Omoju

Parallel / Concurrent Sessions II

Structural Transformation Through Technology

Macroeconomic Modelling for Policy Formulation in the Digital Age

Climate Resilience and Green Digital Finance

Room 1: Climate Resilience and Green Digital Finance

Session Chairperson: Prof Bright Eregha**; Co-Chairperson:** Dr Emmanuel Agiaye

Paper No.	Paper Title	Author(s)
NAMM-1100125	Leveraging Carbon Credit for Agricultural Development in Nigeria	• Chibuike Onyinyechi; Udomi Ediomi
NAMM-1100425	Bridging The Gap: The Role of Financial Inclusion in Addressing Environmental Challenges and Advancing Sustainability in Sub-Saharan Africa	• Joshua C. Onwe; Christopher U. Kalu
NAMM-1101225	Electricity Access, Usage Patterns, And Alternative Energy Solutions in Halls of Residence: A Case Study of Abdulsalami Abubakar Postgraduate Hall at The University of Ibadan, Nigeria	• Moneke Makuachukwu U.; Olusanya E. Olubusoye
NAMM-1101825	Assessing The Dynamics of Liquefied Petroleum Gas in Household Energy Transition: A Case Study of Accessibility, Pricing, And Adoption in Nigeria	• ATOBA, Yinka J.; Olusanya E. Olubusoye
NAMM-1102425	Fiscal Policy and Low Carbon Investment: A Sectoral Analysis in Nigeria	• Kechiro Ambro-Moye; Philip O. Alege; Queen-Esther Oye
NAMM-1101525	Intelligent System for Waste Management with Deep Learning Techniques	• Oluwafemi S. Abioye; Olalekan Akintande; Joseph A. Olasupo; Ubokobong O. Udofia; Oluwafemi L Bisiriyu

NAMM-1102725	Climate Shocks, Agricultural Production and Business Cycles in Nigeria	• Pam Peace Ann; Philip O. Alege
NAMM-1102625	Anomaly Detection in Electricity Consumption Patterns in the Residential Areas of the University of Ibadan	• Ghazal K. Atinuke; Olusanya E.Olubusoye; Ismael T. Abdulateef

Room 2: Macroeconomic Modelling for Policy Formulation in the Digital Age
Session Chairperson: Prof Afeez Salisu**; Co-Chairperson:** Engr Emmanuel Falobi

Paper No.	Paper Title	Author(s)
NAMM-1103325	DYNAMIC PRICING MODELS FOR ENERGY TARIFFS: INSIGHTS FROM METERING DATA	• J. A. Olasupo; Oluwafemi S. Abioye; Eze Blessing
NAMM-1101725	Asymmetry Volatility Modeling of Nigerian Stock Prices with Some Selected Distribution of Innovations	• Ilori A.K
NAMM-1101925	Integrating AI and Macroeconometric Models for Real-Time Monetary Policy Simulation in Nigeria	• Afolabi Daniel
NAMM-1102125	Optimal Monetary Policy using Reinforcement Learning: An Application to the South African Economy	• Oluwanbepelumi E. Olanubi; Sijuola O. Olanubi;
NAMM-1102825	A Systematic and Critical Review of the Application of CGE Models in Nigeria	• Eyitemi A. Fasanu-Adegboye; Abiola Akande; Christiana O. Hassan
NAMM-1103125	Business Cycles and Monetary Policies in Nigeria	• Ogunkola Damilola; Philip O. Alege
NAMM-1103225	The Effect of Policy Shocks on Output over the Business Cycle in Nigeria	• Wasiu Adekunle; Bisola M. Kolawole
NAMM-1103525	Commitment to Disinflation and Bond Market Dynamics in Nigeria: Do Expectations Matter?	• Auwal Isah; Oscar W. Anthony

Closing Ceremony

- Communique - Chairman, LOC – Prof. Christopher U. Kalu
- Closing Remarks –President NAMM – Prof. Philip O. Alege
- Vote of Thanks – Vice President NAMM

Local Organising Committee (LOC)

Prof. Olusanya E. Olubusoye	LOC Chairman
Dr Emmanuel Agiaye	Programmes Chair
Dr Iredele Ogunbayo	Publicity and Communications Chair
Dr Queen-Esther Oye	Finance and Resource Mobilisation Chair
Mr Tubi O. Theophilus	Logistics Chair

Members of the LOC

Prof. Chris U. Kalu	LOC Member
Dr Lucy Nwobi	LOC Member
Mr Udochukwu Nwachukwu	LOC Member
Mr Emmanuel Obijole	LOC Member

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Preface

It is with great pleasure that I present these Proceedings of the 4th Annual International Hybrid Conference of the Nigerian Association of Macroeconomic Modellers (NAMM), held on 26-27 November 2025 at the University of Ibadan, under the theme: *"Policy Innovation for Economic Recovery, Structural Transformation and Digital Macroeconomic Modelling."*

The conference was conceived at a pivotal moment in Nigeria's economic history, when policymakers, researchers and development practitioners are confronted with the interconnected challenges of economic recovery, inflationary pressures, structural transformation, climate change, technological disruption, and the growing influence of artificial intelligence and digital finance on economic systems. Against this backdrop, NAMM provided a platform for rigorous intellectual engagement on how innovative policy frameworks and modern macroeconomic modelling tools can support evidence-based decision making in Nigeria and across Africa.

These proceedings reflect the richness and diversity of contributions made during the conference. The volume brings together keynote addresses, panel discussions, presentations of the NAMM Macroeconomic Models, invited papers, and peer-reviewed research papers covering a wide range of contemporary issues, including artificial intelligence in macroeconomic modelling, digital finance, monetary and fiscal policy, exchange rate dynamics, climate-resilient growth, food and nutrition security, energy transition, financial innovation, and regional economic integration.

A notable highlight of this conference was the emphasis on integrating emerging technologies into macroeconomic analysis. Discussions on Artificial Intelligence, Machine Learning, Digital Macroeconomic Modelling, and AI-enhanced DSGE and CGE frameworks underscored the growing need for more adaptive, data-driven and policy-relevant modelling approaches that can respond to the complexities of modern economies. The conference equally reinforced the importance of building indigenous modelling capacity and developing home-grown analytical tools that adequately reflect Nigeria's unique economic structure and institutional realities.

The quality of the papers and discussions captured in this volume demonstrates the expanding frontiers of macroeconomic modelling research in Nigeria and beyond. The contributions provide valuable insights for academics, policymakers, central bankers, government institutions, development partners, postgraduate students, and all stakeholders interested in advancing evidence-based economic policy formulation.

As Programmes Chair, I wish to express my sincere appreciation to all authors, presenters, discussants, session chairpersons, keynote speakers, panelists, reviewers, members of the Local Organizing Committee, and our esteemed partners and sponsors whose support made this conference a success. Their commitment to scholarly excellence and policy engagement has enriched the quality of these proceedings and strengthened the growing community of macroeconomic modelers in Africa.

It is our hope that the ideas, analyses and policy recommendations presented herein will stimulate further research, deepen collaboration between academia and policy institutions, and contribute meaningfully to Nigeria's pursuit of sustainable economic growth, structural transformation and inclusive development.

On behalf of the Conference Organizing Committee, I commend these proceedings to scholars, researchers, policymakers and practitioners, trusting that they will serve as a useful reference and catalyst for future advances in macroeconomic modelling and economic policy analysis.

Dr. Emmanuel Agiaye
Programmes Chair, NAMM 2025 International Conference

Overview of the 4th Annual Nigerian Association of Macroeconomic Modellers (NAMM) International Hybrid Conference

1.0 Introduction

The 4th Annual Conference of the Nigerian Association of Macroeconomic Modellers (NAMM) convened in hybrid format (physical and virtual) on November 26-27, 2025, at the Subomi Conference Center, University of Ibadan, Nigeria. The conference, themed "Policy Innovation for Economic Recovery, Structural Transformation and Digital Macroeconomic Modelling," brought together economists, policymakers, researchers, and students to address Nigeria's most pressing economic challenges through advanced modeling techniques.

The Conference Sub-Themes are Impact of AI on Digital Macroeconomic Modeling; Structural Transformation through Technology; Macroeconomic Modeling for Policy Formulation in the Digital Age; Climate Resilience and Green Digital Finance and Sub-regional, Regional and Global Macroeconomic Policy Modeling Coordination and Implementation Efforts

The two-day conference was preceded by a comprehensive two-day pre-conference training workshop held on Monday, November 24th and Tuesday, November 25th, 2025. The event attracted diverse participants including NAMM association members, academics, government officials from various ministries, departments and agencies (MDAs), postgraduate students, representatives from the international community, and members of the press.

The conference featured enriching speeches, technical presentations, goodwill messages from partner organizations, keynote addresses, and panel discussions. Day one commenced with opening ceremonies, followed by Plenary Session I and Technical Sessions 1 and 2, focusing on emerging issues in the use of AI in macroeconomic modeling. The evening featured a cocktail reception to facilitate networking and relationship building among participants.

The Day 1 of the conference commenced with Dr. Emmanuel Agiaye welcoming distinguished guests including former president Professor Adeola Adenikinju, current President Professor Philip Alege, the conference LOC Chairman Professor Olusanya Olubusoye, the Conference Chairman Professor Anthone E. Akinlo, and several distinguished guests.

Day two included Plenary Session II, Technical Session III on climate resilience and green digital finance, invited paper presentations, and a distinguished panel session on sub-regional, regional, and global macroeconomic policy modeling. The conference concluded with closing remarks from the President, Professor Philip Olasupo Alege, followed by the Annual General Meeting where administrative reports were presented, the executive committee was dissolved, and new executives were nominated.

1.1 NAMM President's Welcome Address by Professor Philip Alege

The President of the Nigerian Association of Macroeconomic Modellers, Professor Philip Olasupo Alege, FNAMM gave the welcome address.

In his opening remarks, Professor Alege articulated NAMM's core mission and vision:

NAMM's Mission Statement: To create an enabling environment for building relevant macroeconomic models for Nigeria.

Vision Statement: To provide evidence for policy and economic decisions through macroeconomic modeling in Nigeria.

Professor Alege emphasized the critical significance of the conference, noting that macroeconomic models guide understanding of growth, stability, and policy design in modern economies. He stressed that Nigeria and Africa cannot escape this modern approach in the face of evolving development challenges. Highlighting that macroeconomics is not a static science but has been evolving over decades in response to a changing world, he identified uncertainty as a key challenge. Citing the IMF (2025), he noted that "uncertainty has surged to an exceptionally high level globally and is likely here to stay," underscoring the need to rethink how models particularly in growing economic environments reflect real-world dynamics.

He recommended a movement toward home-grown models with inclusivity, factoring in the informal sector, social variables, and governance structures unique to Nigeria. Professor Alege positioned NAMM's role as providing a platform for dialogue between modelers and policymakers and building local capacity, with the ultimate goal of developing models that engineer the prosperity Nigerians deserve. He called for embracing innovation through adaptation of AI, machine learning, and other emerging technologies.

The President concluded with a call to action: move from theory to practice, ensure models speak to growth, equity, stability and resilience, and collaborate across academia, policy, and industry.

1.2 Conference Chair Opening Remarks by Professor Anthony E Akinlo

To set the tone for conference deliberations, the Conference Chairman, Professor Akinlo, represented by Professor Adedokun, introduced the theme and its relevance to Nigeria's current economic context. He stated that in today's rapidly evolving global landscape, economies worldwide face unprecedented challenges—from lingering effects of global pandemics to geopolitical tensions, climate change, and internal and external security challenges. The need for innovative policy solutions has never been more pressing.

The Chairman emphasized that for nations striving for sustainable growth and development, there must be a willingness to rethink traditional economic frameworks and embrace new approaches that drive recovery, transformation, and resilience. He outlined that the conference would explore cutting-edge ideas, share empirical evidence, and engage in meaningful discussions on harnessing the power of digital macroeconomic modeling to inform smarter, more effective policies.

Critical topics to be addressed included:

- How digital tools and data analytics enhance economic forecasting and policy design?

- The role of structural transformation in driving sustainable economic growth
- Innovative policy frameworks for promoting economic recovery amid global uncertainties

The full text of the opening remarks is presented as follows:

Distinguished Guests, Esteemed Speakers, and Fellow Participants,

It is my pleasure to welcome you all to the fourth edition of this timely and crucial conference organized by the Nigerian Association of Macroeconomic Modellers with a central theme “Policy Innovation for Economic Recovery, Structural Transformation, and Digital Macroeconomic Modelling in Nigeria”. Please permit me to acknowledge and appreciate the members of the local organizing committee for their efforts towards organizing an international conference of this magnitude at this crucial time. In addition, I appreciate all the guests honoring the invitation to grace this occasion, despite their tight schedules. Lastly, my profound appreciation to all the presenters who contributed by submitting their well-researched articles for presentation at this conference. I must state clearly here that your contributions have given this year’s conference an indelible mark in the history of events.

In today's rapidly evolving global landscape, economies around the world are facing unprecedented challenges. From the lingering effects of global pandemics to geopolitical tensions and climate change, coupled with internal and external security challenges across the globe, the need for innovative policy solutions has never been more pressing. For nations striving for sustainable growth and development, we must rethink traditional economic frameworks and embrace new approaches that can drive recovery, transformation, and resilience.

The theme of this conference—Policy Innovation for Economic Recovery, Structural Transformation, and Digital Macroeconomic Modelling—perfectly encapsulates the urgent need for forward-thinking policies. As we gather here, we will explore cutting-edge ideas, share empirical evidence, and engage in meaningful discussions on how to harness the power of digital macroeconomic modelling to inform smarter, more effective policies.

Over the next few days, we will dive into critical topics such as:

- How digital tools and data analytics can enhance economic forecasting and policy design

- The role of structural transformation in driving sustainable economic growth

- Innovative policy frameworks for promoting economic recovery in the face of global uncertainties

- The potential of emerging technologies to reshape macroeconomic landscapes

This conference brings together some of the brightest minds in the field—policymakers, researchers, and industry experts—who will share their insights and expertise. We will have the opportunity to learn from each other's experiences, challenge our assumptions, and build new partnerships that can drive meaningful change.

Once again, I would like to extend my deepest gratitude to our esteemed speakers, panellists, and organisers for their hard work and dedication in making this conference a reality. Your contributions will undoubtedly shape the future of economic policy and inspire innovative solutions to the challenges we face.

To all participants, I encourage you to engage actively in the discussions, ask tough questions, and collaborate with your peers. Let this conference be a platform for sparking new ideas and forging partnerships that will lead to impactful policy innovations.

With that, I declare the conference open and wish you all a productive and enriching experience. Let us work together to shape the future of economic policy and drive sustainable growth for all.

Thank you.

Prof. Anthony E. Akinlo

1.3 Goodwill Messages from Partner Organizations

Innovation Lab for Policy Leadership in Agriculture and Food Security (PiLAF)

Professor Adegbenga Adekoya, co-principal investigator of PiLAF, delivered a goodwill message on behalf of the organization, which has been an integral partner of NAMM for the past two years. He stressed the importance of NAMM becoming a "go-to place" for government consultation before policy pronouncements, highlighting that policy-making without consulting modelers often leads to negative outcomes in Nigeria.

Professor Adekoya challenged NAMM to be proactive by analyzing state and federal budgets to advise the government on their implications, noting that the conference theme is particularly apt given Nigeria's current economic situation. He expressed keen interest in discussions surrounding innovative policies for transforming Nigeria's agri-food system and enhancing food security, areas where collaboration between PiLAF and NAMM could yield significant policy insights.

West Africa Monetary Agency (WAMA)

Mr. Boima S. Kamara, Director General of the West Africa Monetary Agency, represented by Dr. Santigie Mohamed Kargbo, Senior Economist at WAMA, delivered a goodwill message emphasizing the relevance of AI-driven modeling and forecasting for WAMA's key mandate of enhancing and coordinating monetary cooperation among member states.

Dr. Kargbo noted that most ECOWAS member states' economies are characterized by undiversified production and export structures, making them highly exposed to external shocks. He emphasized that AI-driven modeling and forecasting will be crucial for harmonizing policy processes as the region moves toward adopting a single currency. WAMA expressed its intention to institutionalize these practices and strengthen its relationship with NAMM, demonstrating commitment to further collaboration in advancing regional macroeconomic modeling capacity.

Central Bank of Nigeria (CBN)

Dr. Usman Okpanachi, Director of the Statistics Department at CBN, represented by Dr. Joseph Tawose, also delivered a goodwill message acknowledging the importance of the conference for the CBN, which is transitioning toward becoming a more forward-looking organization where modeling and forecasting play vital roles.

He emphasized that the conference is critical in bridging the gap between academia and institutions like ministries, departments, and agencies (MDAs), allowing these institutions to benefit from cutting-edge university research. This partnership approach ensures that theoretical advances in modeling translate into practical policy applications.

Analyst Data Services and Resources Limited (ADSR)

Miss Peace Olubere, representing the Chief Operating Officer of ADSR, a partner organization, delivered a goodwill message highlighting that ADSR sits at the center of the shift toward policy innovations using

digital tools because they work directly with data, which forms the bedrock for effective models and forecasting.

She emphasized the evolution from descriptive and predictive modeling to prescriptive policy innovations, noting that the conference represents a major paradigm shift for the country. ADSR's involvement underscores the growing collaboration between private sector data analytics firms and academic modeling institutions.

1.4 Fellowship Award

In recognition of decades-long invaluable contributions to the growth and advancement of macroeconomic modeling in Nigeria, Africa, and globally, NAMM presented a Fellowship Award to Professor Olusanya E. Olubusoye, a distinguished academic and statistician recognized for expertise in econometrics, big data analytics, and statistical modeling. Professor Olubusoye, who has made significant impacts in shaping statistical research and policy across Africa, was represented at the ceremony by his spouse. This recognition reflects NAMM's commitment to honoring those who have advanced the field and inspired future generations of modelers.

1.5 Keynote Addresses

Day One Keynote Address

Dr. Muhammed Musa Tumala, former Director of the Monetary Policy Department of the Central Bank of Nigeria (CBN), delivered the first keynote address virtually on the topic "Policy Innovation for Economic Recovery and Digital Macroeconomic Modeling". Dr. Tumala emphasized the theme's criticality to Nigeria's future, given the global economic transformation driven by digital skills and infrastructure.

He argued that Nigeria's persistent macroeconomic vulnerabilities are symptoms of underlying structural imbalances, necessitating fundamental transformation rather than superficial adjustments. Recalling the 2008 global financial crisis, Dr. Tumala noted that it revealed limitations in standard macroeconomic indicators and prompted the CBN to develop data analytics capabilities to handle unstructured data, often referred to as "big data."

Dr. Tumala challenged NAMM to develop "next-generation models" specifically tailored to Nigeria's data landscape, including integration of high-frequency data. He proposed establishing a working group on digital models for structural transformation to advance the modeling agenda in Nigeria.

Day Two Keynote Address

Dr. Usman Okpanachi, Director of the Statistics Department at the Central Bank of Nigeria, represented by Dr. Joseph Tawose, delivered the second keynote address focusing on "Data Modeling and Digital Technologies in Macroeconomic Policy". Dr. Okpanachi emphasized that traditional policy tools are increasingly insufficient for addressing the complex forum of contemporary policy-making.

He highlighted Nigeria's historical reliance on crude oil revenues and the global inconsistency of commodity markets, underscoring the urgent need for structural reforms influenced by quality policy informed by robust data. He stressed that data quality depends fundamentally on institutions, with organizations like the National Bureau of Statistics (NBS) and the CBN at the core of data collection,

analysis, and provision.

Dr. Okpanachi noted the importance of introducing digitalized economic modeling tools such as artificial intelligence into policy analysis. However, he cautioned that it is crucial to maintain human oversight and intelligently communicate with AI systems rather than blindly accepting their outputs. He advocated for the convergence of advanced data analytics, sophisticated economic modeling, and digital technologies to enhance policy precision and agility. The keynote emphasized that effective policy relies on high-quality data and that the CBN has recently begun introducing AI into its modeling processes, representing a significant step forward for evidence-based policy-making in Nigeria.

The full text of the keynote address 2 is given as follows:

A Keynote Address of the Director, Statistics Department, Central Bank of Nigeria, Dr. Okpanachi Moses Usman, presented by Dr. Tawose Joseph, Deputy Director, Statistics Department, at the 4th International Conference of Nigerian Association of Macroeconomic Modeler (NAMM), held today November 24, 2025, at the University of Ibadan.

All Protocols are duly respected

1. It is my pleasure to present the keynote address at this international conference of the Nigerian Association of Macroeconomic Modellers (NAMM). I consider it as a privilege and honour to be part of this gathering where renowned scholars and industry leaders share knowledge. The theme of the conference ***"Policy Innovations for Economic Recovery, Structural Transformation, and Digital Macroeconomic Modelling"*** cannot be more apt at any other time than now, as Nigeria stands at a critical point in its economic post-recovery trajectory. The nation is currently navigating a complex landscape of persistent economic challenges, while simultaneously embarking on ambitious reform agenda. At the forefront of this strategic direction is the "Renewed Hope Agenda", complemented by the comprehensive National Development Plan (NDP) 2021-2025 with the overarching aim to propel Nigeria towards becoming a trillion-dollar economy within the next decade. This vision is predicated on leveraging the country's vast human and natural resources. I sincerely appreciate the NAMM, WAMA And AfDB for organizing the conference at this critical time.
2. Ladies and gentlemen, permit me to share some insights on the sub-theme of this conference. Specifically, I would like to speak on the role of data, modelling and digital technologies in shaping macroeconomic policy framework in Nigeria. As you may be aware, the global economic environment is increasingly intricate, volatile, and interconnected. Traditional policy tools are proving to be insufficient in addressing these new complex developments. The recent convergence of advanced data analytics, sophisticated economic modelling, and transformative digital technologies offers unprecedented capabilities for policymakers. These tools enable a deeper understanding of economic phenomena, more accurate prediction of future trends, and the ability to influence economic outcomes with enhanced precision, agility, and inclusivity.
3. There is no gain saying that Nigeria's history is marked by broad based potentials often hampered by structural weaknesses, particularly a heavy reliance on crude oil, which prices and demand are sceptible to global uncertainty. This has contributed to persistent issues like a substantial productivity gap. Until recently, the economic environment was characterized by high inflation, slower than expected growth, and exchange market demand pressures presenting a complex dilemma for the authorities. This underscores the need for deeply coordinated fiscal and structural reforms that complement monetary policy, as have been done by the current administration.

4. Distinguished ladies and gentlemen, the effectiveness of any policy is influenced by the quality of data which is very critical for macroeconomic modelling towards addressing key policy challenges. Quality data depends largely on the institutions and the nature of attention by relevant stakeholders. In Nigeria, the Nigeria Bureau of Statistics (NBS) is charged with the core responsibility of producing data albeit other institutions, like the Central Bank of Nigeria (CBN) is not only a consumer of data, but has been deeply involved in the collection, collation, processing and dissemination of data for stakeholders. The Bank is also into robust policy modelling using its analytical infrastructure to model, estimate and project key parameters for its policy loss functions. This, therefore, underscores the interconnectedness between and among these concepts that remains the bedrock of this conference.

5. As you may be aware, the world is experiencing an unprecedented "data deluge" driven by the Information and Communication Technology (ICT) revolution. Economic data has moved beyond traditional surveys to Big Data, characterized by immense volume, high velocity, and diverse variety. This enables "now-casting," providing real-time insights into current economic conditions and allows economists to move from population averages to a deeper, more atomic-level understanding of individual behaviour. For Nigeria, this agility allows for more timely and precise interventions, reducing the severity of economic shocks and supporting the identification of new trends for diversification.

6. However, data abundance does not automatically translate into effective utilization. The sheer volume often exceeds human analytic capacity and capabilities, and the risk of generating biased or misinformed policy remains. This highlights the critical need to invest not just in raw data collection infrastructure, but equally in advanced analytical tools, such as Artificial Intelligence and Machine Learning, and in developing skilled human capital. Furthermore, responsible data governance, privacy, and ethical frameworks must be paramount to ensure efficiency, fairness and sound public trust.

7. Macroeconomic modelling has also evolved overtime significantly, spurred by the fundamental challenge that economic relationships are not the same when policy environments change. This has led to the development of sophisticated models that incorporate individual-level choices, financial systems, and heterogeneity. Recognizing that no single model can perfectly describe the complex reality of an economy, a Suite of Models approach is essential. This strategy uses multiple diverse models to enhance the robustness of projections, allowing for cross-validation, comprehensive risk assessment, and ultimately, augmenting human judgment in policy decisions.

8. Digital technologies are fundamentally reshaping how governments design and implement trade, investment, and public service programs. E-governance, which leverages digital tools to deliver services, is a critical component for achieving efficiency, transparency, and accountability. Initiatives like the Bank Verification Number (BVN) and digital currency enhance financial inclusion and transparency. Concurrently, strategic investments in digital infrastructure, such as expanding fiber optic networks and fostering skills development in coding and data science, are vital for establishing a robust and innovative digital economy ecosystem.

9. The confluence of advanced data analytics, sophisticated economic modelling, and transformative digital technologies offers a powerful synergy to accelerate national development. By leveraging real-time data to pinpoint the root causes of issues like inflation and using granular data to design highly targeted job creation programs, policy can become more effective and inclusive. This strategic integration of technology with governance reforms is

essential for unlocking the full potential of the nation's economic development strategies.

10. As I conclude this keynote address, I look to the esteemed scholars, industry leaders, and policymakers gathered here to translate these concepts into actionable strategies. My expectation is that your collective deliberations over these two days will yield concrete recommendations, practical roadmaps for leveraging Big Data, refining our Suite of Models approach, and accelerating digital governance reforms in our dear country. Let us work together to forge a policy framework that is not only agile and data-informed, but truly resilient, inclusive, and capable of delivering sustainable prosperity for our nation.

Thank you for your kind attention

Dr. Okpanachi Moses Usman, Director Statistics Department Central Bank Of Nigeria

2.0 Presentation of NAMM Models

A highlight of the conference was the presentation of three NAMM models, representing significant advances in the association's capacity to provide evidence-based policy recommendations:

2.1 NAMM Model I: Integrating AI with the Small Macroeconomic Model for Real-Time Monetary Policy Simulation in Nigeria by Prof. Olusanya E. Olubusoye & Dr Ephraim Ogbonna.

Dr. Ahamuefula Ephraim Ogbonna presented the NAMM Model I on integrating AI with the small macroeconomic model for real-time monetary policy simulation in Nigeria on behalf of his co-author Professor Olusanya E. Olubusoye.

The study examines the integration of Artificial Intelligence (AI) into a Small-Scale Macroeconomic Model (SSMM) for Nigeria. The motivation stems from the increasing need to improve the forecasting performance, adaptability, and policy relevance of macroeconomic models in environments characterized by data scarcity, structural breaks, and nonlinear economic relationships. The proposed framework combines conventional macroeconomic equations with AI-driven expectation formation and hybrid correction procedures. The model consists of five core equations representing aggregate demand, money demand, aggregate supply, exchange rate determination, and monetary policy behavior. Empirical evaluation demonstrates that AI-enhanced specifications outperform traditional macroeconometric approaches across most model equations. Hybrid AI-structural formulations also improve performance in some areas, particularly the IS curve and Phillips curve, although deterioration is observed in the LM and UIP equations. Simulation results under a 5 percent currency appreciation scenario illustrate the macroeconomic implications of exchange rate movements. The findings suggest that AI can serve as a valuable complementary tool for macroeconomic modelling, provided integration remains theory-consistent and carefully validated.

1.0 Introduction

1.1 Macroeconomic Modelling

Macroeconomic modelling represents a systematic representation of the aggregate economy. It involves the construction of a structured and internally coherent framework that links key sectors of the economy through behavioral equations and accounting identities. Such models formalize theoretical relationships and empirical regularities in order to understand economic dynamics and simulate policy

outcomes.

Macroeconomic models also serve as tools for policy analysis, forecasting, and scenario evaluation. They enable analysts and policymakers to:

- Evaluate the impacts of economic shocks.
- Explore counterfactual scenarios.
- Examine alternative policy paths.
- Quantify economic trade-offs.
- Predict short- and medium-term outcomes.
- Improve the evidence base for macroeconomic management.

1.2 Macroeconomic Modelling in a Small Open Economy

The structure of a macroeconomic model must adapt to the realities of the economy being modelled. Nigeria, as a small open economy, is characterized by:

- High import dependence.
- Commodity-driven export earnings.
- Exposure to global financial conditions.
- Recurring structural shocks.

Accordingly, macroeconomic models for Nigeria should explicitly account for:

- Exchange rate dynamics.
- External balances.
- Capital flows.
- Exchange rate pass-through effects.

Such models incorporate openness, external vulnerability, and domestic rigidities, thereby enabling more realistic assessments of monetary, fiscal, and exchange-rate policy transmission mechanisms.

A Small-Scale Macroeconomic Model (SSMM) is particularly useful in this context because large-scale models require extensive datasets and numerous parameters. SSMMs capture the essential macroeconomic dynamics while remaining practical for policy simulations under data-constrained environments.

2. Motivation for AI Integration

The integration of AI into macroeconomic modelling is motivated by several considerations.

2.1 Data Scarcity and Structural Breaks

Macroeconomic datasets frequently exhibit missing observations, structural changes, and regime shifts. AI algorithms are capable of learning from sparse and unstable datasets and can outperform conventional econometric methods under such conditions.

2.2 Model Gaps in Policy Environments

Frequently updated macroeconomic models are required for effective policymaking. AI techniques can address structural and data limitations by:

- Automating model updates.

- Improving forecasting precision.
- Capturing nonlinear policy transmission mechanisms.

2.3 Complex Policy Interactions

AI methods such as neural networks and ensemble learning algorithms can accommodate multidimensional interactions among fiscal, monetary, and external-sector variables. These dynamics are often oversimplified in conventional small-scale macroeconomic models.

2.4 Evidence-Based Policy Making

AI-driven models provide enhanced pattern-recognition capabilities and adaptive learning mechanisms. These features strengthen empirical foundations for assessing the impacts of monetary policy in real time.

2.5 Continuous Model Updating

AI integration permits the development of hybrid macro-econometric systems capable of updating model parameters automatically as new data become available. As a result, policy-relevant models remain timely, context-specific, and responsive to changing macroeconomic realities.

3. Stylized Facts for Nigeria (2010–2024)

A review of Nigeria's macroeconomic performance over the period 2010–2024 reveals several notable patterns:

- Real GDP increased from ₦15.1 trillion (2010–2014 average) to ₦18.4 trillion (2020–2024 average), although growth rates weakened from 1.93 percent to 0.16 percent.
- Inflation rose from 9.43 percent to 18.62 percent, indicating increasing price instability.
- The exchange rate depreciated substantially from ₦155.5/$ to ₦611.5/$.
- Interest rates increased from 18.13 percent to 21.66 percent.
- Broad money supply more than doubled during the period.

These trends highlight the growing complexity of Nigeria’s macroeconomic environment and underscore the need for improved modelling approaches.

4. Literature Review

The development of Small-Scale Macroeconomic Models emerged as an attempt to bridge the gap between excessively large macroeconometric systems and oversimplified theoretical frameworks.

Among the earliest open-economy SSMMs was the model developed by Dornbusch (1976), which employed a simple price-setting mechanism and remains a foundational reference. Later contributions expanded the traditional IS-LM framework by incorporating inflation persistence, as demonstrated by Stone et al. (2005).

Researchers subsequently developed both backward-looking and forward-looking open-economy SSMMs, including: Allen et al. (2003), Doménech et al. (2001) and Tanuwidjaja and Meng (2005).

Modern SSMM development is dominated by New Keynesian open-economy frameworks that incorporate: Forward-looking behavior, Nominal rigidities and Rational expectations.

Applications have been widespread across advanced economies, including United States: Rudebusch (2000), Lansing (2000), United Kingdom: Batini and Haldane (1999), Garratt et al. (2003).

Emerging-market applications include: Morana (2005), Dreger and Marcellino (2007), Martínez et al.

(2002), Cagas et al. (2006).

In Nigeria, early modelling efforts relied upon large-scale macroeconometric systems such as Adenikinju, Busari and Olofin (2009), although their effectiveness was constrained by data limitations.

Subsequent research shifted toward smaller models, including: Nkoro and Uko (2018), who developed a 19-equation macroeconometric model, Olofin et al. (2014), who developed a small-scale framework for policy analysis and Olofin, Salisu and Tule (2020), who introduced expectations, oil-price uncertainty, and unemployment dynamics.

Recent innovations include: Bayesian VAR models with stochastic volatility, Deep Reinforcement Learning approaches, Mean-field game frameworks, Large Language Model (LLM)-based economic agents.

5. AI-Integrated Macroeconomic Modelling Framework

The AI integration framework follows a four-stage process:

Stage 1: Data Preparation: Load time-series data.

Stage 2: Train Expectation Models: Fit XGBoost models to expected values.

Stage 3: Train Residual Learners: Fit XGBoost models to model residuals.

Stage 4: Simulation: Run the macroeconometric model pipeline and apply hybrid corrections for expectations.

6. Model Specification

The proposed model contains five equations:

1. IS Curve (Aggregate Demand)
2. LM Curve (Money Demand)
3. Phillips Curve (Aggregate Supply)
4. Uncovered Interest Parity (Exchange Rate)
5. Monetary Policy Rule (Interest Rate Setting)

Variable Definitions



, where: = real GDP; = potential output

Additional variables include: : price level; : nominal money; : inflation rate; : real exchange rate; : nominal interest rate and : monetary policy rate

6.1 IS Curve



This specification contains forward-looking and backward-looking components, the real interest rate , and the lagged real exchange rate.

Theoretical Expectations

- : higher real interest rates reduce output.
- : under the paper's sign convention, an appreciation reduces output.

-  : indicates forward-looking demand behavior.
- Stability generally requires:

\lambda_1+\lambda_2 \le 1 \]【1-0ac868】 --- # 6.2 LM Equation \[m_t-p_t=\tau_1 y_t^g+\tau_2 i_t+\tau_3 e_t+\varepsilon_t^m

Real money balances are assumed to depend on real income, nominal interest rates, and the exchange rate.

Expected Signs:



Positive income effects reflect transaction demand, while interest rates and exchange rates capture opportunity-cost effects.

6.3 Aggregate Supply (Phillips Curve)



This equation incorporates forward-looking inflation expectations, backward-looking inflation persistence, output-gap effects, and exchange-rate pass-through.

Implications

- close to one implies strongly forward-looking inflation.
- The coefficients on expected and past inflation sum to unity, implying a vertical long-run Phillips curve.
- Exchange-rate changes influence inflation through import-price channels.

6.4 Exchange Rate (UIP) Equation



The real exchange rate depends on expected future exchange rates and real interest-rate differentials.

Expected Signs



Higher domestic real interest rates relative to foreign rates are expected to appreciate the domestic currency.

6.5 Monetary Policy Rule



The Central Bank is assumed to set interest rates in response to: Output gap, Expected inflation, Exchange rate developments and Monetary policy rate.

Following the tradition of Woodford (2003), policy adjustment is gradual and interest-rate smoothing is

present.

7. Estimation Methodology

The model is estimated using Ordinary Least Squares (OLS) with quarterly data covering 2010:Q1 to 2024:Q4.

Sample Structure

Sample	Period
Full Sample	2010:Q1-2024:Q4
Training Sample	2010:Q1-2023:Q4
Test Sample	2024:Q1-2024:Q4

Diagnostic Measures

The study evaluates performance using:

- A priori sign checks.
- Actual-versus-simulated comparisons.
- Theil's U statistic.
- Root Mean Square Percentage Error (RMSPE).



$$RMSPE = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left(\frac{Y_t^s - Y_t^a}{Y_t^a}\right)^2}$$

AI vs TRADITIONAL EXPECTATIONS COMPARISON

Equation	AI RMSE	Traditional RMSE	Percent Improvement
IS Curve	6.0717	6.3310	4.10
LM Curve	0.0852	0.1623	47.52
Phillips Curve	0.5052	3.9222	87.12
UIP	0.0160	0.0933	82.83
Policy Rule	0.0000	2.2708	100.00

The AI-enhanced models outperform traditional specifications across all equations. The largest gains emerge in the Phillips Curve, UIP, and policy-rule equations, demonstrating AI's ability to capture nonlinear dynamics and expectation-formation processes.

The AI-generated inflation expectations closely track observed inflation throughout the sample period, indicating substantial predictive capability.

The hybrid specification produces significant gains for the IS and Phillips equations but performs worse for the LM and UIP equations. These findings suggest that hybridization is beneficial in some contexts but may distort exchange-rate expectation formation and money-market dynamics.

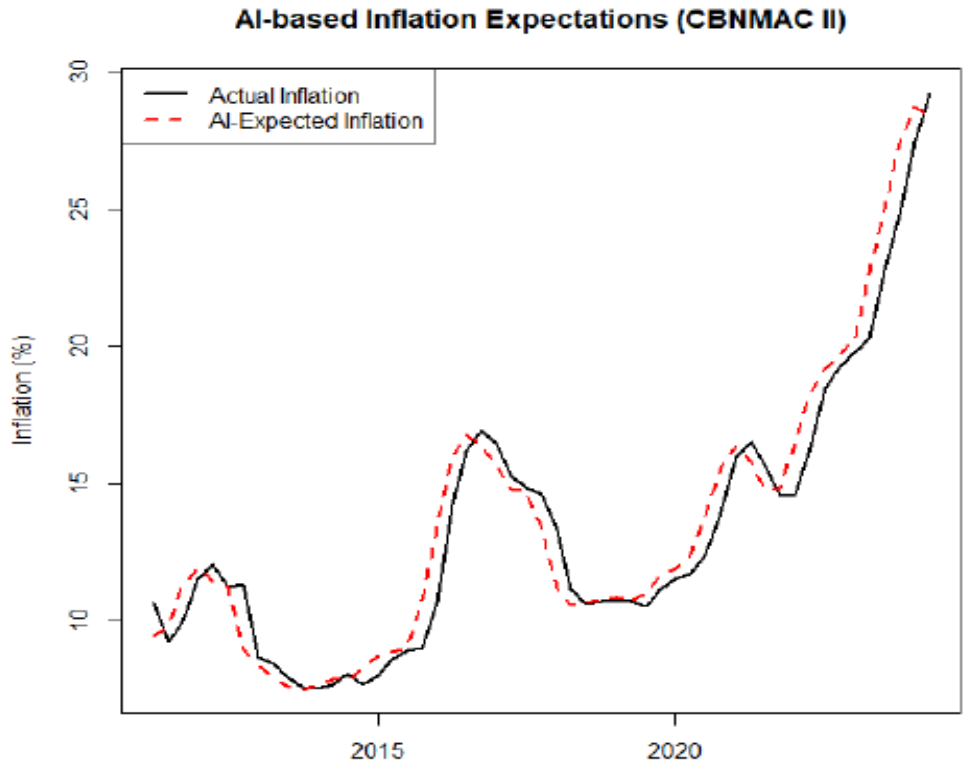
The simulation indicates that:

1. IS shocks become increasingly negative, suggesting that currency appreciation weakens aggregate demand through reduced competitiveness.

2. LM shocks remain persistently high, implying tighter monetary conditions.

3. Phillips Curve and UIP responses diverge, reflecting mixed macroeconomic adjustments involving inflationary pressures and declining exchange-rate expectation shocks.

Actual versus AI-based Inflation Expectations



Structural vs Hybrid Comparison

Equation	Structural RMSE	Hybrid RMSE	Percent Improvement
IS Curve	6.1613	1.3474	78.13
LM Curve	0.0869	0.0952	-9.55
Phillips Curve	0.4996	0.3556	28.82
UIP	0.0162	0.0441	-172.42

- The hybrid model dramatically improves IS Curve performance, reducing RMSE by 78%
  - indicates strong gains in modelling output–interest dynamics
- Phillips Curve accuracy also improves by 29%, showing better inflation–unemployment representation
- LM Curve worsens slightly (–9.6%)
  - hybrid approach adds noise to money–market dynamics
- UIP performance deteriorates sharply (–172%)
  - hybridization may be unsuitable for exchange-rate expectations modelling

Simulation: 5% Currency Appreciation

Date	Real EXR	IS shock	LM shock	PH shock	UIP shock
2023-01-01	4.84	-	8.45	-	5.07
2023-04-01	4.80	-1.55	8.45	21.6	5.07
2023-07-01	4.79	-2.99	8.44	23.1	5.05
2023-10-01	4.79	-2.32	8.43	25.6	4.61

- IS shocks become increasingly negative, implying that currency appreciation dampens aggregate demand through reduced competitiveness
- LM shocks stay persistently high, suggesting monetary conditions tighten as appreciation affects liquidity and money demand dynamics
- Phillips and UIP shocks diverge (rising inflationary pressures accompany falling exchange-rate expectation shocks), showing mixed macroeconomic adjustments.

8. Conclusion

The study demonstrates that AI integration substantially enhances macroeconomic modelling accuracy. AI methods are particularly effective in capturing nonlinear and rapidly evolving macroeconomic relationships. Hybrid AI-structural formulations can significantly improve weakly performing equations and provide a complementary mechanism for enriching representations of macroeconomic interactions. However, the deterioration observed in the UIP and LM equations suggests the existence of structural incompatibilities. AI-based feature fusion may distort exchange-rate expectations and money-market equilibria when not properly aligned with economic theory. Consequently, AI integration should be selective, theory-consistent, and empirically validated. Overall, AI offers transformative potential for macroeconomic modelling. Nevertheless, successful implementation requires careful attention to theoretical coherence, interpretability, robustness testing, and policy relevance before the resulting models can be deployed for practical policy analysis.

2.2 NAMM Dynamic Stochastic General Equilibrium (DSGE) Model II: AI-Enhanced DSGE Modeling by Prof. Philip O. Alege, Dr. A. A. Adegboye, Dr. Queen-Esther Oye and Dr. Dauda Musa

Dr. A.A Adegboye presented the NAMM DSGE Model II on an AI-enhanced Dynamic Stochastic General Equilibrium (DSGE) model on behalf of the development team – Professor Philip O. Alege, Dr. Queen E. Oye and Dr. Dauda Musa. He emphasized that the model is designed for policy analysis in Nigeria and potentially other West African countries. The project aims to build a conventional DSGE model for the Nigerian economy while benefiting from machine learning techniques to improve forecasting accuracy, parameter estimation, and scenario building capabilities.

The presenter explained that integrating machine learning tools with DSGE models can effectively address non-linearities in economic relationships and uncover hidden economic interactions that are challenging to identify when relying strictly on log-linearized DSGE systems. Machine learning allows

for handling more variables simultaneously, generating early warning signals for economic stress, and producing additional synthetic data through training algorithms.

This project represents an ongoing initiative to develop a Nigeria-focused augmented DSGE model that integrates internal dynamics, external shocks, and machine learning to strengthen local capacity for policy-relevant forecasting. The initiative aims to position Nigeria for globally competitive modeling and invites collaboration from institutions such as the IMF, World Bank, African Development Bank (ADB), and ECOWAS. Plans include capacity building programs for postgraduate students to ensure sustainability of modeling expertise.

2.3 NAMM Computable General Equilibrium (CGE) Model III by Mr O.T. Tubi, Mr Abiola Akande and Mr Iredele Ogunbayo.

Mr. Tubi O. Theophilus presented the NAMM CGE Model III on behalf of the development team, Mr. Abiola Akande and Mr. Iredele Ogunbayo. Mr. Tubi noted that it is the third major model presented at NAMM conferences, following Dynamic Stochastic General Equilibrium (DSGE) and Dynamic General Equilibrium (DGE) models. The presentation was structured in two parts: a foundational section covering the model's background, literature review, and methodology, and a second section demonstrating its application through policy scenario simulation.

Model Foundation and Structure

The model is based on an adapted version of the International Food Policy Research Institute (IFPRI) 2021 Social Accounting Matrix (SAM), which was expanded to 46 activity sectors and includes emissions tracking. The modeling was conducted using the GENPACK software platform, a standard tool for CGE analysis.

The core assumptions of the CGE model include perfect competition in markets, rational behavior by economic agents, constant returns to scale in production, and market clearing conditions. The model specification was adopted from Hurage et al. (2018) and extended with previous works, utilizing Keynesian closures that allow unemployment to be endogenously determined—a critical feature for capturing Nigeria's labor market realities.

A notable innovation in this model is the disaggregation of the oil and gas industry sector into five sub-sectors: crude oil and natural gas, refineries, petrochemicals, other refinery products, and emissions. This disaggregation better reflects the structure of the Nigerian economy and allows for more nuanced policy analysis of the energy sector. The final model structure is divided into nine blocks and contains 32 structural equations.

Policy Scenario Simulation: Energy Subsidy Removal

The team presented a policy scenario testing the CGE model's performance using an energy subsidy removal simulation, comparing its impact against a baseline forecast. The simulation confirmed that the model reflected economic intuition, showing that increased energy prices lead to higher production and consumption costs, increased cost of living, and improved government fiscal balances.

The simulation, conducted using run-dynamic modeling techniques, revealed complex short-run and long-run effects:

Short-run Effects:

- GDP contraction due to increased production costs

- Consumer Price Index (CPI/inflation) increases reflecting higher energy costs passed through the economy
- Government financial standing improved significantly due to cessation of subsidy payments

Long-run Effects:

The analysis revealed more complex dynamics in the medium to long term. While fiscal gains from the reform appeared substantial initially, they proved short-lived. Higher production costs reduced taxable consumption across sectors, and sectoral contractions occurred as businesses adjusted to higher energy input costs. Consequently, government savings declined steeply in the medium to long term, highlighting the importance of complementary policies to sustain fiscal gains from subsidy removal.

Policy Implications

The simulation underscored the macroeconomic vulnerability created by Nigeria's lack of economic diversification. Without diversification, subsidy removal could lead to greater fiscal vulnerability, which would increase demands for social protection as more people fall below the poverty line. This creates crowding-out effects on other sectors and increases pressure on public investment, potentially undermining long-term growth prospects.

The presentation sparked important discussions about model verification and the role of modeling in policy analysis. Participants emphasized that models should not enslave users; rather, when results deviate from a priori expectations, rigorous verification and interrogation of the model are essential. If thorough checking confirms the results, it may indicate that received economic theory requires updating—an essential process for the growth of knowledge. The key is ensuring that models relate to current reality to gain the attention of policymakers and inform effective policy decisions.

AI Integration for Macroeconomic Modeling of Nigeria

Mr Iredele Ogunbayo presented this pioneering work focused on creating a starting point for robust discussions on macroeconomic modeling using AI-generated expectations. The presentation emphasized that this is a work in progress intended to inform policy through innovative approaches to expectation formation in macroeconomic models.

The presentation outlined a general framework for AI integration in macroeconomic modeling involving data preparation, model training, and using AI to generate economic expectations instead of traditional rational or adaptive expectations approaches. A critical innovation is training residuals to incorporate uncertainties, leading to a hybrid model that can be used for policy simulations while accounting for the inherent uncertainty in economic forecasting.

3.0 Plenary on AI and Digital Macroeconomic Modeling

Focused on Impact of AI, LLMs, and new computational methods on forecasting. Exploring advances in digital macroeconomic modelling techniques, including the use of big data, machine learning, and real-time analytics to improve forecasting, scenario analysis, and policy evaluation and the future of Central Bank modelling and forecasting tools.

Topic: Artificial Intelligence and New Digital Tools for Forecasting.

The plenary was chaired and moderated by Dr. Joseph Tawose (CBN). The panelists include Professor Olu Ajakaiye, Dr. Michael A. Adebisi (former CBN Director), Miss Peace Orubere (IDSR), and Prof. Christopher Ulua Kalu (NAMM Vice President).

Core Consensus: AI delivers faster, more accurate forecasts and can handle large, complex datasets. However, human control, theoretical guidance, and ethical frameworks are paramount.

Key Insights:

- **Prof. Ajakaiye:** Warned against becoming "slaves to AI," stressing that humans must articulate the system's description and expectations.
- **Prof. Kalu:** Emphasized the need to "domesticate" AI applications to capture Nigeria's unique cultural context and behavioral patterns, distinguishing results from those in Western countries.
- **Capacity Building:** Panelists universally called for investment in training, quality data, and transparent frameworks to maximize AI's benefits.

4.0 Panel Session: Sub-Regional, Regional and Global Macroeconomic Policy Modeling

A distinguished panel session chaired by Professor Adeola Festus Adenikinju explored critical issues related to sub-regional, regional, and global macroeconomic policy modeling coordination and implementation efforts. The panelists included: **Professor Adeola Festus Adenikinju** (Chair) - Former President of the Nigerian Economic Society and Pioneer President of NAMM, highly influential economist specializing in energy economics, macroeconomic modeling, and development policy; **Professor Olu Ajakaiye** - Executive Chairman of the African Center for Shared Development Capacity Building; **Dr. Santigie Mohamed Kargbo** - Economist and researcher from Sierra Leone, affiliated with WAMA and the University of Cape Town; **Dr. Ahamuefula Ephraim Ogbonna** - Leading Nigerian econometrician and research fellow at the Center for Econometrics and Applied Research, ranked in the top 3% of economists in Nigeria and top 8% in Africa and **Dr. Okafor representing Dr. Afolabi Olowoekere**.

4.1 The Evolution of Macroeconomic Modeling Requirements

Professor Adenikinju opened the session by highlighting the necessity for macroeconomic modeling to evolve in response to the interconnected modern world, characterized by instant global shocks, shifting supply chains, and rapid financial market reactions. He argued that traditional linear models are insufficient for capturing contemporary economic complexities.

The modern economy requires dynamic, multi-sectoral, network-based, and data-rich models that capture interdependence across countries, sectors, and markets. The panel's objective was to explore how Africa, and Nigeria specifically, can build modeling systems that are "smart, integrated, adaptive, and relevant to real-world complexities."

4.2 Understanding Structural Changes in African Economies

Professor Adenikinju emphasized that the "first challenge of a modeler is to be conversant with developments around the economy." Modelers must understand how the economy works and how those workings are changing. They must remain intimately connected with developments in their economy and society to create models that reflect current reality and gain the attention of decision-makers.

He observed that the structure of economies in the West African region has changed dramatically over the last decade, with services now emerging as the dominant sector, shifting away from agriculture. He characterized this trend as the "premature tertiaryization of our economy," noting the conspicuous absence of strong secondary (manufacturing) activities, which typically serve as the transition stage after the primary sector in traditional development models.

A concerning aspect of this structural change is that much of the new service sector consists of low-productivity "distributive trade," which generates poor employment outcomes and contributes to growing poverty and intergenerational poverty. The labor-absorbing capacity of the economy has been adversely affected by the transition from primary to tertiary sectors, leading to a system that builds human capacity for a non-existent labor market. This results in the "Japa syndrome," where the brightest and best people exit the continent—a phenomenon Professor Adenikinju termed "modernized slavery."

Furthermore, while African economies are moving away from similar agricultural production structures, they remain weakly interconnected, as the goods being traded are often imported items, effectively servicing other people's economies rather than building regional value chains.

Professor Adenikinju concluded by stressing that modelers must account for the character of engagement with the rest of the world, particularly the financial system's significant impact on the economy. The influence of "hot money" or transient investors means that exchange rates are now often dependent on the financial system rather than the real sector. Consequently, modelers must incorporate instability and the prominence of financial systems into their modeling assumptions.

4.3 The Necessity of Regional and Global Models for Africa

Dr. Santigie Mohamed Kargbo addressed why regional and global policy models are important for Africa. He emphasized that considering the interconnectedness of economies through trade, investments, and financial flows, it is time to move beyond country-specific models to consider how global spillovers and regional linkages influence economic behavior.

Global spillovers, such as shifts in global commodity demand and changes in advanced economies' monetary policy, have significant impacts on commodity-producing countries like those in Africa. For example, decisions by the U.S. Federal Reserve or European Central Bank affect capital flows to African markets, influencing exchange rates and domestic interest rates across the continent.

Dr. Kargbo stressed that single-country models are insufficient for assessing major decisions like joining the African Continental Free Trade Area (AfCFTA). Such decisions require regional and global models for comprehensive cost-benefit analysis that accounts for trade diversion effects, rules of origin implications, and dynamic gains from expanded market access.

Regional models are also essential for policy coordination within ECOWAS, especially for initiatives such as the adoption of a single currency. Such coordination necessitates harmonization of fiscal, monetary, and trade policies across member states—an impossibility without robust regional modeling frameworks.

Dr. Kargbo recommended practical approaches such as using Global Vector AutoRegressive (GVAR) models or multi-country Computable General Equilibrium (CGE) models to capture interlinkages between countries and analyze how shocks in one country (such as a commodity price shock in Nigeria) affect trading partners like Ghana or broader regional dynamics.

4.4 The Role of Big Data, AI, and Machine Learning in Regional Modeling

Dr. Ogbonna explained how big data, AI, and machine learning can improve the accuracy of macro-modeling. He characterized big data by its volume, velocity, and veracity, combining structured and unstructured data that traditional econometric models cannot adequately handle.

AI and machine learning offer platforms to extract valuable information from unstructured data, such as sentiments driving economic and financial variables, for inclusion in modeling frameworks. AI-driven processes generate useful indices like the economic policy uncertainty index and geopolitical risk measures, enhancing modeling capacity.

Dr. Ogbonna elaborated that AI frameworks offer more realistic ways to capture nonlinearities than existing econometric models and provide platforms for exploring multiple scenarios to inform policy decisions. AI also addresses the problem of using lagged structured data by allowing combination of different data types, including information from social media and other real-time sources, to improve model quality and inform timely decisions.

The complexity of traditional macroeconomic models, exemplified by those with close to 200 equations, often resulted in poor forecasts. AI now simplifies modeling work by providing real-time data and estimates closer to reality, enabling "nowcasting" for immediate policy insights.

4.5 Institutional Frameworks for Integrating Modeling into Policy

Dr. Okafor acknowledged that modeling efforts are currently fragmented and primarily confined to individual spaces within Nigeria, limiting their policy impact. He proposed a new institutional framework beginning with domesticating modeling efforts by setting up standardized modeling teams within key agencies like the Ministry of National Planning, Central Bank of Nigeria, and Federal Ministry of Finance.

Dr. Okafor advocated for creating synergy among domestic modeling teams to integrate their unique models by reviewing underlying peculiarities and developing a unified national modeling framework. He observed that a comprehensive regional model for Africa does not currently exist. Although the IMF makes estimates for the region, African countries themselves lack a unified model to validate or challenge those estimates—a significant gap in regional policy capacity.

The panel supported the idea of coordination, with participants challenging agencies to present their models at forums like the Nigerian Economic Society (NES) conferences. Economists should use their models to assess and project the impact of government budgets, providing independent analysis that can inform public debate and policy decisions.

4.6 The Role of Stakeholders and Capacity Building

Regarding the role of key stakeholders and the Nigerian Economic Society in facilitating the building and operationalizing of national and regional models, the panel confirmed that NES is effectively engaging in capacity building and knowledge sharing. This helps non-modelers understand modelers' work and reduces resistance to policy recommendations based on modeling insights.

The panel suggested that NES should intensify capacity building through online training programs and specialized meetings, particularly at the state level, to analyze the implications of government budgets before and after passage. This would democratize access to modeling insights and strengthen evidence-based policy-making across all levels of government.

4.7 Challenges in Regional Modeling

Dr. Kargbo and other panelists identified the major challenge to building regional and subregional models as the lack of uniform and quality data across the subregion. Data collection frameworks are inconsistent across countries, with different methodologies, frequencies, and levels of reliability.

Dr. Okafor reiterated that data availability and quality are fundamental challenges, emphasizing that obtaining quality data is expensive and requires sustained investment. He advocated for relevant stakeholders within ECOWAS and the African Union (AU) to prioritize data issues through partnerships and collaboration, potentially establishing a regional data infrastructure that serves all member states.

5.0 Summary of Technical Sessions and Paper Presentations

5.1 Session on Climate Resilience and Green Digital Finance

Fiscal Policy and Low-Carbon Investments: A Sectoral Analysis in Nigeria

Kechiro Ambro-Moye, Philip O, and Queen-Esther Oye presented research examining the relationship between fiscal policy instruments and low-carbon investments in Nigeria. The study was motivated by observable climate change patterns and the increasing impact on Sub-Saharan African regions.

The presenters noted that global temperatures have been rising, with 2014 to 2024 representing the warmest decade according to the World Meteorological Organization (2024). Rising temperatures threaten to push millions into poverty, especially in developing countries, motivating adoption of low-carbon energy solutions using fiscal policies like carbon taxes and green subsidies.

The study was grounded in three theoretical frameworks:

- Keynesian fiscal theory supporting government involvement in promoting low-carbon investments
- Pigouvian theory advocating environmental taxes on goods produced using fossil fuels
- Green growth theory focusing on merging economic growth with environmental protection

Using panel data from 2017 to 2024, fully modified least squares estimation revealed that tax revenue reduced low-carbon investment by discouraging private sector investment, while GDP per capita had a strong positive effect, indicating that wealthier countries tend to invest more in low-carbon technologies.

Impulse response function analysis showed that shocks in tax revenue initially reduced low-carbon investment, while shocks in government expenditure positively affected low-carbon investment. Total debt shocks led to declines in low-carbon investments, and foreign direct investment shocks initially produced negative responses that later became mildly positive. GDP per capita shocks consistently led to positive responses in low-carbon investment.

The study recommended that Sub-Saharan African countries adopt forward-looking green fiscal frameworks, introduce green tax incentives that encourage rather than discourage low-carbon investments, and promote regional cooperation on climate finance and low-carbon technology transfer.

Intelligence System for Waste Management Using Deep Learning

Oluwafemi S. Abioye presented research on developing an intelligent system for waste management using deep learning techniques, addressing problems like waste affecting climate and contributing to land degradation. The research focused on developing an automated waste recognition and classification system to classify waste into categories like plastic, paper, and organic materials to aid in sorting and recycling.

The methodology involved collecting real-time image data of waste from the University of Ibadan campus and comparing traditional machine learning models (Support Vector Machine - SVM) with deep learning models (EfficientNet and DenseNet) for classification accuracy.

Results showed that the traditional SVM model performed better than the two Convolutional Neural Network (CNN) models, which was attributed to the small dataset size of only 1,710 images. EfficientNet

performed poorly due to insufficient training data, a finding supported by existing literature on deep learning data requirements. DenseNet demonstrated good precision for identifying food waste compared to EfficientNet.

Recommendations for future work included using larger and more diverse datasets (ideally in the thousands of images), implementing the system in real-time waste management operations, conducting public awareness campaigns for waste separation at source, and expanding the scope to multi-class classification covering more waste categories.

5.2 Session on Energy Access and Efficiency

Electricity Access and Usage Patterns in University Residential Halls

Monek Makuachukwu U. presented research on electricity access, usage patterns, and alternative energy solutions in residential halls at the University of Ibadan, Nigeria. The study was motivated by Nigeria's longstanding electricity supply challenges, which significantly affect students' comfort, studying conditions, and academic productivity.

Using a mixed-methods approach combining structured questionnaires for quantitative data and key informant interviews for qualitative insights, the research focused on Abdul Salam Abubakar Postgraduate Hall. Results showed that electricity was available with interruptions approximately 96.6% of the time. When interrupted, 47.4% of respondents experienced outages lasting 4 to 8 hours daily.

The period of highest electricity unavailability and peak demand was identified as evenings between 6:00 p.m. and 12:00 a.m.—precisely when most students require lighting for studying. Students primarily used electricity for charging devices and laptops for academic work.

Recommendations included upgrading and modernizing electrical infrastructure, deploying solar hybrid and mini-grid systems to provide backup power during grid outages, and exploring university-private sector partnerships for financing sustainable energy solutions.

Anomaly Detection in Electricity Consumption Patterns

Ghazal K. Atinuke presented research on anomaly detection in electricity consumption patterns in residential areas of the University of Ibadan to establish factors contributing to energy inefficiency, particularly energy theft, which is significantly underreported in Nigeria. The research used 12 years of transactional data totaling 138,310 transactions and adopted machine learning techniques for anomaly detection.

Temporal patterns showed an increasing consumption trend over time with seasonal fluctuations corresponding to the academic calendar. Using the Isolation Forest algorithm, 43 accounts were identified as anomalous. Comparing multiple detection methods, the Interquartile Range (IQR) approach was most sensitive, flagging 34.9% of accounts as anomalies.

The consensus method across multiple algorithms suggested that 22% of accounts (312 accounts) were potentially anomalous, indicating a significant gray area for revenue leakage. This finding has major implications for tertiary institutions and electricity distribution companies seeking to improve revenue collection.

Policy recommendations included targeted auditing of flagged accounts for tertiary institutions, implementing real-time monitoring using Internet of Things (IoT) devices, enhancing data quality

through better metering infrastructure, and supporting forecasting efforts to more judiciously channel resources for infrastructure maintenance and expansion.

5.3 Session on Food and Nutrition Security

Assessment of Policies for Promoting Food and Nutrition Security in Nigeria

Dr. OluSola Omoju presented work-in-progress research assessing policies for promoting food and nutrition security in Nigeria. The presentation noted that Nigeria's food security situation is worsening, with projections indicating food-insecure Nigerians could rise to 82 million by 2030. Despite numerous government policies focused on agricultural productivity enhancement and income support programs, the situation continues to deteriorate, raising questions about the effectiveness of these interventions.

The research aimed to analyze food consumption patterns of Nigerian households and determine the economy-wide and food/nutrition impacts of policy interventions using a general equilibrium approach. Analysis using the 2018-2019 Living Standards Measurement Survey revealed that rice and prepared cereal products are more consumed in urban areas, often at the expense of traditional staples like yams and cassava.

A significant finding was that 87% of rural and 80% of urban households consume food away from home, a factor often neglected in policy formulation. Diets are generally dominated by staple foods, accounting for over half of energy intake. The research estimated that 22% of Nigerian households experience a food gap, with the highest gap surprisingly in the southeast region—a finding requiring further investigation. Furthermore, 85% of households consume less than the WHO-recommended benchmark of 400 grams of fruits and vegetables daily.

Caloric intake increases with income, and as income rises, households shift toward rice and prepared cereal products from traditional cereals, with fat intake also increasing. Regarding diet quality, richer households have more diverse diets, consuming both more nutritious and more unhealthy foods compared to low-income households—a nuanced finding that challenges simplistic assumptions about income and nutrition.

Analysis of two policy scenarios using the CGE model indicated that broad input subsidies for the entire agricultural sector had more positive impacts on real GDP and investment, while targeted input subsidies for smallholder producers had greater impacts on household income and food consumption. This suggests the need for differentiated policy approaches depending on whether the objective is aggregate growth or poverty reduction.

Next research steps include linking the CGE model with a nutrition model to analyze the impact of policy scenarios on the nutritional content of consumed food and adopting a dynamic modeling approach to assess long-term impacts. Key conclusions include the necessity of considering food consumed away from home in policy formulation, recognizing clear regional and income group variations in food security, and understanding that income improves food security but does not necessarily improve nutrition—requiring targeted nutrition interventions beyond income support.

5.4 Session on Financial Innovation and Economic Transformation

Financial Innovation, Financial Market Dynamics and Economic Transformation in Nigeria

A presentation delivered on behalf of the Group Managing Director of Cari Assets Management Limited examined financial innovation's role in Nigeria's economic transformation. The presentation defined

financial innovation as the adoption of new financial instruments and products, driven primarily by technology.

Financial innovation through avenues like mobile payments, digital banking, and fintech platforms contributes to financial inclusion, operational efficiency, risk management, and economic growth in Nigeria. Recent market dynamics, including Monetary Policy Rate (MPR) decisions by the CBN, foreign exchange reforms, and the Eurobond market, significantly affect capital market indicators like fixed income yields and equity valuations.

Financial innovation drives economic growth through multiple channels: reducing transaction costs, boosting financial inclusion by reaching previously unbanked populations, encouraging entrepreneurship through alternative financing mechanisms like crowdfunding and peer-to-peer lending, and deepening credit markets by improving risk assessment and lending efficiency.

The channels for transformation identified include digital payment infrastructure development, market and monetary policy reforms that create enabling environments for innovation, and government digitalization initiatives that demonstrate use cases and drive adoption.

Challenges to financial innovation and market dynamics in Nigeria include regulatory uncertainty, limited broadband infrastructure especially in rural areas, cybersecurity concerns, exchange rate volatility that affects investor confidence, and the relative shallowness of Nigeria's capital markets compared to peer countries.

The presentation concluded by emphasizing that financial innovation is central to Nigeria's economic transformation, requiring leveraging of technology alongside robust, transparent, and accurate data. The mathematical formula offered was: Innovation + Strong Markets = Sustainable Economic Transformation.

6.0 Key Findings and Observations on Panel Sessions, Technical Sessions and Paper Presentations

6.1 On AI and Digital Macroeconomic Modeling

- There is a need for revised models that incorporate oil uncertainty to reflect Nigeria's oil dependence and sensitivity to global oil price shocks, ensuring models capture the full impact of commodity price volatility on fiscal positions and economic growth.
- The use of AI for incorporating high-frequency data is justified, as AI frameworks like XGBoost allow for using monthly inflation data to predict quarterly GDP, offering more informative and timely insights than quarterly figures alone.
- Innovative economics is replacing traditional economics, made possible by emerging technologies such as AI, the Internet of Things, and cloud computing. AI is applicable not only in forecasting but also in "nowcasting," utilizing agent-based models, AI-driven models, or DSGE models for real-time prediction and analysis.
- Integrating machine learning tools with DSGE models can effectively address nonlinearities and uncover hidden economic interactions that are challenging to identify when relying strictly on log-linearized DSGE systems. Machine learning allows for handling more variables, generating early warning signals for economic stress, and producing additional synthetic data through training algorithms.

- The complexity of traditional macroeconomic models, exemplified by those with close to 200 equations, often resulted in poor forecasts. AI now simplifies modeling work by providing real-time data and estimates closer to reality, enabling better policy decisions.
- A general framework for AI integration in macroeconomic modeling involves data preparation, model training, and using AI to generate expectations instead of traditional methods. The final step is to train residuals to incorporate uncertainties, leading to a hybrid model suitable for policy simulations.

6.2 On Data and Institutional Capacity

- There is a critical need for collecting quality data and precisely predicting economic trends in an era of severe economic shocks and rapid structural changes.
- Data quality depends fundamentally on institutions, with organizations like the National Bureau of Statistics (NBS) and the Central Bank of Nigeria at the core of data collection, analysis, and provision for robust policy modeling.
- Digital technologies, including e-governance initiatives like the Bank Verification Number (BVN) and digital currency (eNaira), are fundamentally reshaping public service programs to achieve efficiency, transparency, and accountability.
- Modeling efforts are currently fragmented and primarily confined to individual spaces within Nigeria, limiting their collective policy impact and necessitating better coordination mechanisms.

6.3 On Structural Transformation and Economic Challenges

- The labor-absorbing capacity of the Nigerian economy has been adversely affected by the transition from primary to tertiary sectors, leading to a system that builds human capacity for a non-existent labor market. This results in the "Japa syndrome," where the brightest and best talents exit the continent—characterized as "modernized slavery."
- African economies are moving away from similar agricultural production structures but remain weakly interconnected, as the goods being traded are often imported items, effectively servicing other people's economies rather than building regional value chains and productive capacity.
- The character of engagement with the rest of the world must be accounted for by modelers, particularly the financial system's significant impact on the economy through "hot money" flows and transient investors, meaning that exchange rates are now often dependent on the financial system rather than the real sector.
- New sectors like technology and fintech are emerging but remain dependent on external resources and equipment due to the collapse of secondary (manufacturing) activities, limiting their potential to drive broad-based economic transformation.

6.4 On Regional and Global Modeling

- Considering the interconnectedness of economies through trade, investments, and financial flows, it is time to move beyond country-specific models to consider how global spillovers and

regional linkages influence economic behavior. Global and regional models are essential because the world functions as a "global village."

- Single-country models are insufficient for assessing major decisions like joining the African Continental Free Trade Area (AfCFTA), requiring regional and global models for comprehensive cost-benefit analysis that accounts for dynamic effects and spillovers.
- A comprehensive regional model for Africa does not currently exist. Although the IMF makes estimates for the region, African countries lack a unified model to validate or challenge those estimates—a significant gap in regional policy capacity.

6.5 On Cryptocurrency and Digital Finance

- Nigeria only transacts in, rather than produces, cryptocurrencies, as all initial coin offerings are quoted abroad. Nearly 50% of Nigerian cryptocurrency transactions are based on Bitcoin, and the ban on Binance restricted access to detailed transaction data needed for comprehensive analysis.
- A study found that AI adoption caused distortions in the labor market, particularly in the service sector where the policy shock was introduced, leading to displacement or job loss across low, medium, and high labor skill categories—highlighting the need for proactive labor market policies.

6.6 On Food Security and Nutrition

- A significant finding revealed that 87% of rural and 80% of urban households consume food away from home—a factor often neglected in policy formulation but critical for understanding consumption patterns and nutrition outcomes.
- Diets are generally dominated by staple foods, accounting for over half of energy intake. An estimated 22% of Nigerian households experience a food gap, with the highest gap surprisingly in the southeast region. Furthermore, 85% of households consume less than the WHO-recommended benchmark of 400 grams of fruits and vegetables daily.
- Regarding diet quality, richer households have more diverse diets, consuming both more nutritious and more unhealthy foods compared to low-income households—a nuanced finding indicating that income alone does not guarantee better nutrition.
- Caloric intake increases with income, and as income rises, households shift toward rice and prepared cereal products from traditional cereals, with fat intake also increasing, raising concerns about nutrition transition and non-communicable diseases.

6.7 On Climate and Environmental Policy

- Low-carbon investment represents an important alternative financing option outside of traditional climate financing to address the relationship between fiscal policy and environmental sustainability.
- If waste is not managed intelligently and sustainably, it will negatively affect the environmental ecosystem and overall sustainability, requiring innovative solutions like AI-driven waste classification systems.

7.0 Closing Plenary (Roundtable Panel)

7.1 Conference Recommendations

7.1.1 On Model Development and Innovation

- NAMM should lead the development of "next-generation models" specifically tailored to Nigeria's unique realities and data landscape, incorporating collaboration with statisticians, data scientists, and domain experts across sectors.
- Home-grown models must be developed with inclusivity, factoring in the informal sector, social variables, and governance structures that are often absent from standard macroeconomic models but critical to Nigeria's economic reality.
- AI integration is needed to address common challenges with economic data in Nigeria, such as gaps, structural shifts, and nonlinearity, which traditional models may not adequately capture.
- Nigerian behavioral patterns are highly context-specific and require factoring in cultural and institutional contexts when applying AI models. Distinguishing local results from those in Europe or America is essential to avoid misapplication of foreign modeling approaches.

7.1.2 On Responsible AI Use

- Human expertise and theoretical guidance are essential when incorporating AI, as unguided variable selection can sometimes worsen forecasts. Caution must be taken against becoming "slaves to AI" if human control over the modeling framework is surrendered.
- It is necessary to clearly articulate the system's description and expectations; the machine should not determine the outcomes but should serve as a tool to enhance human judgment.
- AI is a tool and should be used as such. AI-adopted model studies should specify the product or type of AI used in the analysis, such as ChatGPT, XGBoost, or specific neural network architectures, as well as explaining how the data was contextualized for measurability and interpretation.
- Models must be related to current reality to gain the attention of policymakers. When results deviate from a priori expectations, rigorous verification and interrogation of the model are essential. If thorough checking confirms the results, it may indicate that received economic theory requires updating.

7.1.3 On Data and Institutional Frameworks

- Institutions and committees should be involved in shaping data policy at the national level to ensure consistency, quality, and accessibility of economic data for modeling purposes.
- New institutional frameworks should be developed to integrate modeling into the policy cycle, ensuring decisions are based on analytical frameworks rather than intuition or political expediency. A framework beginning with domesticating modeling efforts by setting up standardized modeling teams within agencies like the Ministry of National Planning, Central Bank, and Federal Ministry of Finance was proposed.
- The idea of coordination among modeling agencies was strongly supported. Agencies should present their models at forums like the Nigerian Economic Society (NES) conferences, and economists

should use their models to assess and project the impact of government budgets, providing independent analysis.

- NES should intensify capacity building through online training programs and specialized meetings, particularly at the state level, to analyze the implications of government budgets before and after passage, democratizing access to modeling insights.

7.1.4 On Regional Cooperation and Capacity Building

- Policy coordination is essential within the ECOWAS region, especially for issues like trade improvement and tackling inflation. This coordination is crucial for initiatives such as ECOWAS's movement toward adopting a single currency, necessitating harmonization of fiscal, monetary, and trade policies.

- Relevant stakeholders within ECOWAS and the African Union (AU) should prioritize data issues through partnerships and collaboration, potentially establishing a regional data infrastructure that serves all member states to address the lack of uniform and quality data across the subregion.

- NAMM should maintain the two-day pre-conference workshop as an essential component of future conferences, providing intensive training for participants and building modeling capacity among postgraduate students and early-career researchers.

- NAMM must become a "go-to place" for government consultation before policy pronouncements. Policy-making without consulting modelers often leads to negative outcomes in Nigeria, necessitating proactive engagement with policymakers.

7.1.5 On Cryptocurrency and Digital Finance

- Excessive regulation or prohibition of cryptocurrency transactions was recommended against. The government should implement policies to allow regulated cryptocurrency use to capture tax revenues and improve monetary policy transmission.

- Strengthening the eNaira (Nigeria's Central Bank Digital Currency) to be a competitive currency against cryptocurrencies was proposed, along with establishing macro-prudential surveillance in the crypto market to prevent fraud and excessive capital flight.

- Policymakers should consider the effect of rising prices and recognize that tightening monetary policy (increasing the MPR) in Nigeria can affect digital finance tools and payment methods, requiring careful calibration of policy instruments.

7.1.6 On Labor Market and Technology

- The educational sector should be stimulated to support STEM (Science, Technology, Engineering, and Mathematics) programs, with policies for retraining and reskilling the labor force to adapt to technological change.

- AI technology adoption should focus on augmenting labor rather than replacing it, emphasizing labor-complementary strategies that enhance worker productivity rather than displacing workers, particularly in a high-unemployment environment like Nigeria.

7.1.7 On Food Security and Agricultural Policy

- There is a need to consider food consumed away from home in policy formulation, given that the majority of both rural and urban households consume food outside their homes, affecting both food security and nutrition outcomes.

- Policy must recognize clear regional and income group variations in food security and nutrition. The finding that income improves food security but does not necessarily improve nutrition requires targeted nutrition interventions beyond income support programs.

- The inclusion of security challenges in agricultural research models is essential, as significant security instability, particularly in northern Nigeria, severely impacts farmers' ability to access markets and affects food prices. Neglecting the impact of insecurity, including farmer-herder clashes, in models fails to capture critical constraints on agricultural production.

7.1.8 On Climate and Environmental Policy

- Sub-Saharan African countries should adopt forward-looking green fiscal frameworks that align fiscal policy with environmental sustainability objectives, moving beyond short-term considerations.

- Green tax incentives should be introduced to encourage low-carbon investments, recognizing that poorly designed tax policies can discourage rather than promote environmental sustainability.

- Regional cooperation on climate finance and low-carbon technology transfer should be promoted, recognizing that climate change is a transboundary challenge requiring coordinated responses.

7.1.9 On Research Quality and Academic Standards

- Postgraduate students must satisfy theoretical, statistical, and econometric criteria for plausible results and avoid working in isolation from economic theories. Methodological rigor should not be sacrificed for novelty.

- Researchers should show evidence of heterogeneity across sectors or units when using panel data models and justify the chosen panel data estimator through appropriate diagnostic tests.

- Model diagnostics must be presented to ensure model reliability before interpretation of results. This includes tests for specification, stability, and robustness.

- Robustness analysis should be conducted by using alternative proxies for key variables to confirm that conclusions remain consistent across different measurement approaches.

7.1.10 On Policy Priorities for Modelers

- Modelers were advised to pay particular attention to annual and medium-term fiscal policy, monetary policy decisions (including indicators like the Monetary Policy Rate and Cash Reserve Ratio), foreign exchange reserves, exchange rate regimes, and developments in the energy and petroleum sectors—all critical drivers of Nigeria's macroeconomic performance.

- Policy analysis should go beyond direct effects to capture indirect effects and feedback loops across various sectors, leveraging the strength of general equilibrium approaches to provide comprehensive impact assessments.

8.0 Closing Remarks

Professor Philip Alege, President of NAMM, provided closing remarks expressing profound gratitude for the attendance and rigorous intellectual work accomplished during the conference. He urged participants, especially young researchers and students, to reflect deeply on what they have gained and how they are being prepared to contribute to Nigeria's economic transformation.

The President stressed the critical importance of economic history, noting that understanding the past is essential for comprehending the present and anticipating the future, especially when working with economic data and building models. Historical context provides the foundation for understanding structural relationships and identifying when those relationships are changing.

Professor Alege implored economists to be more open-minded and embrace a fundamental rethink of the profession in light of technological advances and changing economic realities. He encouraged more frequent engagement among members, suggesting a quarterly schedule for sharing ideas, presenting work-in-progress, and maintaining momentum in advancing Nigeria's modeling capacity.

The President emphasized that NAMM's ultimate goal is to build models that engineer the prosperity Nigerians deserve, requiring a movement from theory to practice and ensuring that models speak to growth, equity, stability, and resilience. He called for sustained collaboration across academia, policy institutions, and industry to achieve this vision.

9.0 Vote of Thanks

Dr. Emmanuel Agiaye delivered the vote of thanks for the 4th NAMM 2025 Conference, titled "Policy Innovation for Economic Recovery, Structural Transformation and Digital Macroeconomic Modelling." He acknowledged the transformative insights shared on artificial intelligence, machine learning, fintech, blockchain, and their applications to macroeconomic modeling.

Dr. Agiaye expressed gratitude to all keynote speakers (Dr. Muhammed Musa Tumala and Dr. Usman Okpanachi represented by Dr. Joseph Tawose) for providing intellectual depth and policy relevance to the proceedings. He thanked all panelists and session chairs, particularly Professor Adeola Adenikinju, Professor Olu Ajakaiye, Dr. Santigie Mohamed Kargbo, and Dr. Ahamuefula Ephraim Ogbonna, for providing the intellectual backbone of the conference through their expert contributions.

Special recognition was extended to all paper presenters, including the NAMM model development teams (Mr Iredele Ogunbayo, Mr. Tubi O. Theophilus and colleagues), as well as other researchers who presented their work across technical sessions. Their contributions represent the future of macroeconomic modeling in Nigeria.

Dr. Agiaye thanked the delegates and participants for their active engagement, recognizing them as "policy innovators and change agents" who will translate conference insights into real-world impact. He specifically recognized numerous sponsors and partners, including:

- Analyst Data Services and Resources Limited (ADSR)
- Innovation Lab for Policy Leadership in Agriculture and Food Security (PiLAF)
- School of Industrial Agriculture (SIA), University of Ibadan
- Central Bank of Nigeria (CBN)
- National Bureau of Statistics (NBS)
- Nigerian Communications Commission (NCC)
- West Africa Monetary Agency (WAMA), with special mention of Dr. Santigie Kargbo from Sierra Leone
- African Development Bank (AfDB)
- Nigerian Economic Society (NES)

- African Finance and Economic Association (AFEA)

Dr. Agiaye also acknowledged the media team—including Seyi, Femi, Divine, and Kafayat—and the technical teams, specifically mentioning Dr. Tubi and Chief Eli, for their tireless efforts in ensuring the conference's smooth execution and success.

10.0 Conclusion

The 4th Annual Conference of the Nigerian Association of Macroeconomic Modellers achieved its objectives of advancing the discourse on policy innovation, structural transformation, and digital macroeconomic modeling. The conference successfully brought together diverse stakeholders—academics, policymakers, researchers, and students—to engage in meaningful dialogue on Nigeria's economic challenges and modeling solutions.

The presentations of three NAMM models (AI Integration for Macroeconomic Modeling, AI-Enhanced DSGE Model, and CGE Model 3) demonstrated significant progress in developing indigenous modeling capacity tailored to Nigeria's specific context and data environment. The panel discussions and technical sessions provided rich insights into regional modeling requirements, the role of AI and big data, institutional frameworks for policy integration, and sectoral challenges in areas ranging from food security to climate resilience.

The conference reinforced NAMM's commitment to building models that reflect Nigeria's reality, inform evidence-based policy-making, and contribute to engineering the prosperity that Nigerians deserve. Moving forward, NAMM will focus on implementing the recommendations from this conference, strengthening partnerships with domestic and international institutions, intensifying capacity building efforts, and positioning itself as the premier destination for macroeconomic modeling expertise in Nigeria and West Africa.

The next conference will build on these foundations, continuing NAMM's mission of creating an enabling environment for building relevant macroeconomic models and providing evidence for policy and economic decisions through rigorous macroeconomic modeling.

Technical Sessions and Papers

TECHNICAL SESSION I: MACROECONOMIC MODELLING FOR POLICY FORMULATION IN THE DIGITAL AGE · NAMM INVITED PAPER 1

SESSION CHAIRPERSON: PROF. ADEOLA ADENIKINJU · CO-CHAIR: DR QUEEN-ESTHER OYE

Cryptocurrency and Fiat Monetary Transmission Dynamics in Nigerian Economy: A Bayesian DSGE Approach

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JEL Classification: C11, C51, E12, E32

Keywords: government currency, cryptocurrency, DSGE

Abstract

The evolution of cryptocurrencies and other digital payment systems redefined macroeconomic policy making around the globe. The usage of cryptocurrency as alternative currency has affected the effectiveness of monetary policy. This implies that developments in the cryptocurrency ecosystem is an important consideration in monetary policy-making. The objective of this study is to evaluate the interactions of cryptocurrency and government currency on the Nigerian economy. This study incorporated heterogenous agents with money in the utility function to analyze the response of macroeconomic variables to shocks in preference, productivity, cryptocurrency demand, government currency demand and monetary policy. The cryptocurrency sector was included in the DSGE model estimated through the Bayesian framework. Estimation data set include monthly data from April 2013 to December 2024 on the following observed variables: Bitcoin Price (BTP), Cryptocurrency Capitalization (CRP), Real Gross Domestic Product (RGDP), Real Private Consumption Expenditure (RPCE), Money supply (M2), Inflation Rate (INFR) and Monetary Policy Rate (MPR). The findings indicate a dual relationship between cryptocurrency and domestic currency. There is a substitution effect between cryptocurrency and naira in response to real economic shocks while there is a complementarity effect in response to monetary policy shocks. Currency substitution is driven by economic uncertainties associated with high inflation and naira depreciation. Cryptocurrency ban was ineffective in reducing crypto transactions but credible monetary policy moderates the impact of cryptocurrency speculation on the economy. The study recommends strengthening the regulatory framework by the monetary authorities instead of outright prohibition and the promotion of the eNaira as alternative digital currency to meet currency demand while retaining naira sovereignty.

1. Introduction

The expansion of financial technologies (Fintech) and emergence of artificial intelligence created avenues for financial innovations which led to the blockchain system. In 2008, Satoshi Nakamoto pioneered the birth of cryptocurrency that serves as an alternative to the traditional currency following the release of Bitcoin. By its nature, cryptocurrencies offer decentralized, borderless financial assets with no third-party interference (Ahmed,2024; Joshipura et al.,2025). Through the spread of cryptocurrency, millions of financially underserved people access financial services which is beneficial

in reducing income inequality and poverty (Othman et al.,2020Galanti and Ozsoy,2021; Akande et al., 2024; Joshipura et al.,2025).

The global crypto market has experienced a quantum expansion. Between 2020 and 2024, the global market capitalization for crypto assets grew from $211 billion in 2020 to $3.4 trillion in 2024 (coingecko,2024). This rise in the market was driven by potential high returns, opportunities for investment diversification and wide adoption of crypto assets (IMF,2025). As an alternative to fiat money, some countries have already legalized the usage of cryptocurrency as a medium of exchange. Bitcoin in particular has gained legal tender status in El Salvador since 2021 while Denmark, Japan, France and the US allow Bitcoin to be used to settle transactions (Asimakopoulos et al.,2023). Consequently, companies such as Microsoft and Wikipedia accept cryptocurrency payments and donations.

Cryptocurrency adoption in different countries has been slow due largely to regulatory challenges and potential risks (KPMG & Chainalysis,2025). In the global ranking of cryptocurrency adoption, Nigeria ranks second after India (Chainalysis,2024). Data from Chainalysis shows that Nigerians' cryptocurrency transaction volume stood at $59 billion between June 2023 and June 2024. According to Consensys and YouGov (2024), Bitcoin (62%) is the most traded crypto asset in Nigeria followed by Binance (51%) and Ethereum (41%). Until February 2025 when Securities and Exchange Commission (SEC) approved the launching of cNGN as the foremost stablecoin in Nigeria, all other crypto assets traded by Nigerian investors were issued overseas. This heightens the possibility of falling victim to several risks associated with crypto transactions which may harm countries with weak regulatory environments.

While crypto transactions have been generally judged safe, there are inherent risks in the unregulated crypto market. Mutanda and Nomlala (2025) explains that crypto transactions in unlicensed platforms have been used as a covert avenue to perpetrate fraud and carry out illicit cash movements which leads to capital flight. Similarly, uncontrolled crypto transactions can lead to currency speculation against a domestic currency and fundamentally challenges monetary policy effectiveness by circumventing central bank control (Tomic et al., 2020; IMF,2025). High cryptocurrency adoption can also lead to diversion of funds from regulated banking systems which increase currency volatility (Panigrahi, 2023; Bas et al., 2023). Even so, cryptocurrency can potentially promote financial inclusion and stability if properly integrated into the financial system (Ahmed, 2024; Sadiq et al., 2023).

To ameliorate crypto risks, crypto transactions are usually faced with stringent regulations. In particular, the Nigerian Central bank (CBN) prohibited Nigerian banks from holding crypto denominated assets or liabilities through a circular dated 5th February 2021. Banks were barred from maintaining deposit accounts or rendering financial services to cryptocurrency exchange companies. This ban recorded partial success in deterring cryptocurrency transactions as traders found alternative means of carrying out their transactions outside the banks. This ban has since been revised in December 2023 allowing banks to offer services for only SEC licensed firms (SEC,2024).

Despite Nigeria's prominence in cryptocurrency adoption and its ongoing reforms, empirical studies on macroeconomic implication of cryptocurrency adoption are very sparse. There is a causal belief by the

authorities that cryptocurrency activities destabilize Nigeria's foreign-exchange market. Thus, the monetary authorities placed sanctions on some crypto companies due to illegal currency speculation which affected exchange rate stability in Nigeria (Martinez, and Kale,2025). However, this belief has not been conclusively validated through rigorous empirical analysis. Empirical findings remain divided concerning the impact of cryptocurrency and other virtual assets on the economy. While some studies found a destabilizing effect of crypto activities, others found that it is growth enhancing. Yet, some studies found a negative impact on monetary policy effectiveness (Tomic et al., 2020;Panigrahi ,2023;Obisesan et al., 2024; Bas et al.,2023). This divergence leaves an empirical gap which informs the need for this study. Previous studies had utilized traditional econometric models such as multiple linear regression model, ARDL and VECM using annual data to investigate crypto-economy nexus in Nigeria (Onyeke, 2020; Acho, 2021; Agu ,2021; Fakunmoju et al., 2022; Olorundare, et al., 2023; Safiyanu et al., 2022; Ajibola et al., 2024; Obisesan et al., 2024). None of these studies utilized the DSGE modeling approach. These models failed to capture forward-looking expectations and policy feedback effects that integrate monetary policy transmission mechanisms in the presence of cryptocurrency adoption. Unlike previous empirical models, the DSGE model follows the general equilibrium that captures the interactions between the cryptocurrency sector, household decisions, financial intermediation and output dynamics. The advantage of the DSGE model is further enhanced by its micro-foundation capable of simulating policies. Thus, the objective of this study is to examine the macroeconomic implications of cryptocurrency adoption in the Nigerian economy. The study sought to analyze the dynamic interactions between cryptocurrency and fiat currency and evaluate how cryptocurrency adoption influences output, inflation and monetary policy effectiveness by estimating a Bayesian DSGE model. To the best of our knowledge, ours is the foremost study that incorporated the cryptocurrency sector in a DSGE estimation framework in Nigeria. The rest of the paper is organized as follows, section 2 dwelt on literature review, section 3 explained the methodology, section 4 presented the results while section 5 concludes the paper.

2. Literature Review

2.1. Theoretical Underpinning

This study is anchored on the monetary substitution theory and the New Keynesian Dynamic Stochastic General Equilibrium (DSGE) framework. The monetary substitution theory postulates that in an environment of dual currencies, economic agents tend to substitute between the alternate currencies if there is a potential for higher returns, stable value and ease of transaction. This substitution effect, thus influences the demand for money, inflation and policy transmission (McKinnon, 1982; Tomic et al., 2020). Given the micro-foundational nature of DSGE models, it is apposite to incorporate currency substitution within a DSGE structure that allows for a systematic analysis of how cryptocurrency adoption affects the economy through agents optimizing behaviors under rational expectations and nominal rigidities (Clarida, Galí & Gertler, 1999; Bojaj et al., 2022). Thus, integrating a cryptocurrency sector into a DSGE model captures the interactions between digital and fiat money markets, consumption, investment, and policy instruments. This allows for simulation of how shocks to cryptocurrency adoption or regulation propagate through the economy and influence output, inflation, and interest rates (Bas et al., 2023). This approach provides understanding of the trade-offs between financial innovation, policy effectiveness, and macroeconomic stability in an emerging economy like Nigeria.

2.2. Cryptocurrency and Blockchain technology

Advancement in computing has created blockchain technology that offers opportunities for alternative modes of payment devoid of a third party. Blockchain technology comprises digitally encoded systems that facilitate secure exchange, verification and sharing of transactions among global internet users. It employs encryption that secures transaction details and identities of participants. Transactions within the networks are validated through complex computer algorithms. Verified transactions are time-stamped and grouped into blocks and sequentially connected to form an immutable chain which creates a permanently distributed ledger. Alterations can only be permitted through explicit collective consensus (Okpalaojiego, 2021).

Cryptocurrency can be traced to the release of Bitcoin in 2009 after the 2008 financial crisis. This follows the white paper published by Satoshi Nakamoto (2008). Bitcoin thus became the first digital currency that offers a decentralized alternative to traditional financial systems which eliminated reliance on trusted third parties like banks. At the onset, Bitcoin faced skepticism and concerns over legality and its potential to encourage illicit activities but gradually became acceptable. Though the skepticism had not completely disappeared, the crypto landscape has since expanded dramatically, with over 4,000 cryptocurrencies emerging by 2021. These include altcoins (alternative coins) such as Ethereum, which introduced programmable smart contracts and supported decentralized applications while others focused on higher transaction speeds or different consensus mechanisms (Radanliev, 2024). The evolution of blockchain technology parallels cryptocurrency development. Different categories of Blockchain exist. These include Blockchain 1.0 (Bitcoin's decentralized ledger), Blockchain 2.0 (smart contracts and decentralized virtual machines like Ethereum), and Blockchain 3.0, which integrates IoT and advanced data analytics to support Web 3.0 ecosystems (Radanliev, 2024). Despite these innovations, scalability, energy consumption and security remain challenges.

The decentralization of the financial system of cryptocurrencies reduces the dependence on central authorities which facilitates financial inclusion and enables automation of complex financial activities which increases transparency. In addition, blockchain can secure supply chains and improve healthcare data management (Srivastava et al., 2024). However, there are several downsides of cryptocurrency which is not the case in the traditional financial system. Cryptocurrency prices are highly speculative and subject to dramatic fluctuations based on social media and influencer activity rather than fundamentals. This unpredictability exposes investors to significant financial loss. Most cryptocurrencies and exchanges operate without comprehensive regulatory oversight which increase risks of fraud, scams, and corporate malfeasance (e.g., collapse of FTX and Terra Luna). There are security vulnerabilities where exchanges and wallets are frequent targets for cyberattacks leading to substantial thefts. Many cryptocurrencies lack intrinsic value or economic utility making them resemble speculative instruments or Ponzi schemes, which disproportionately harm less-informed or poorer investors (Radanliev, 2024; Srivastava,2024).

Joshipura et al. (2025) explains how Initial Coin Offerings (ICO) can be used to expand the cryptocurrency ecosystem. ICO provides a novel and efficient fundraising mechanism for blockchain startups and projects. ICOs allow ventures to issue new crypto tokens to investors, raising capital without the lengthy and complex regulatory processes typical of traditional financing methods. ICOs are innovative fundraising mechanisms that bypass traditional finance, democratize investment, and attract global capital inflows to technology-driven ventures. By integrating blockchain and tokenization into entrepreneurial finance, ICOs stimulate innovation and offer a pathway for decentralized

technologies to enter mainstream markets (Joshipura et al. ,2025). However, there are concerns about ICOs regulatory uncertainties, jurisdictional inconsistencies and widespread fraud risks. Joshipura et al. (2025) further warned that high project failure rates, token illiquidity, governance weaknesses, and speculative volatility undermine investor confidence and long-term sustainability of ICOs. Thus, ICOs are disruptive innovations within cryptocurrency expansion which offer alternative financing channels but require robust governance and regulatory safeguards to ensure stability and investor protection.

2.3 Nigeria's Cryptocurrency Landscape and Regulations

Nigeria has emerged as one of the world's leading cryptocurrency markets. Despite the regulatory challenges, Nigeria ranked second in the rate of cryptocurrency adoption. Initially, regulatory actions of CBN (2021) were quite restrictive when they issued a directive barring deposit money banks from operating accounts linked to cryptocurrency trading. This ban was justified by concerns over money laundering, terrorism financing and lack of robust oversight. This significantly disrupted the crypto ecosystem and pushed crypto activities to peer-to-peer (P2P) platforms. Although the measure was meant to safeguard financial stability and protect the depositors, it generated uncertainty for crypto operators and traders. Thus, by 2023 the CBN partially revised its stance which allows crypto transactions under regulatory supervision.

A more comprehensive regulatory framework emerged with the Investment and Securities Act (ISA) 2025 which formally recognized cryptocurrencies as securities under the oversight of the Securities and Exchange Commission (SEC) (Osazuwa,et al., 2024). The SEC introduced licensing requirements for Virtual Asset Service Providers (VASPs), custodial obligations, and strict anti-money laundering and counter-terrorism financing (AML/CTF) standards. This development replaced earlier regulatory ambiguity with structured guidelines that emphasize multi-agency collaboration, investor protection, and market integrity. Some of the anticipated reforms include regulatory clarity on stablecoins, tokenization, and broader institutional participation (Osazuwa,et al., 2024).

Despite the ban on the crypto market in Nigeria, empirical evidence shows that Nigeria's cryptocurrency adoption remained very resilient. According to KPMG and Chainalysis (2025), Nigeria recorded $59 billion in cryptocurrency transactions between July 2023 and June 2024 which accounted for nearly half of Sub-Saharan Africa's total crypto transactions. It is important to note that 85% of Nigeria's transactions were from small-scale retail and professional transfers under $1 million. This implies that cryptocurrency has already been integrated into everyday financial activities rather than purely for speculative use.

However, concerns of systemic risks persist. IMF (2025) warned that threats to financial stability, monetary sovereignty, and economic integrity may become a challenge. These risks include capital flight, circumvention of foreign exchange controls, migration from naira deposits to dollar-pegged stablecoins and fraud facilitated by unregulated P2P transactions. This led to SEC's stricter supervision that mandated local incorporation of exchanges and expanded blockchain analytics for market surveillance. SEC also imposed a 10% capital gains tax, and introduced marketing regulations to protect retail investors.

2.4. Empirical Review

Empirical research on cryptocurrency in Nigeria is very scanty. Even though cryptocurrency is a relatively new development, its role in shaping the financial systems. In this section, we reviewed available Nigerian studies while augmenting with studies outside Nigeria. We note that most of the reviewed studies utilized traditional econometric models such as multiple linear regression, ARDL or VECM using annual data. Others conducted qualitative study based on primary data. None of the reviewed empirical studies utilized the DSGE modeling approach. Onyeke (2020) investigated the effects of cryptocurrency on Nigeria's economic development. The study sought to determine whether cryptocurrency adoption influences key economic variables such as economic growth, illicit financial flows, terrorism financing, and tax revenue. Applying a multiple linear regression model, the study found a positive but statistically insignificant relationship between cryptocurrency and Nigeria's economic development. The study further found that cryptocurrency exerted a weak inverse influence on illicit financial flows, terrorism, and tax revenue. Agu (2021), investigated the economic implications of cryptocurrency adoption across African countries, with emphasis on financial inclusion, economic empowerment, and regulatory challenges. The study found that cryptocurrencies enhance economic empowerment by expanding access to financial services for underserved and marginalized populations, while also enabling cost-effective cross-border transactions. On his part, Acho (2021) investigated the implications of cryptocurrency adoption for Nigeria's financial markets and overall economic performance. The study concentrated on understanding how cryptocurrency influences financial market stability, investor risk perceptions, and market dynamics. Utilizing the GARCH model, the study found that price fluctuations strongly affect transaction volumes with higher volatility relative to conventional assets which exposed investors to risks.

Safiyanu et al., (2022) investigated the effect of cryptocurrency on the exchange rate in Nigeria. Using monthly time series data and ARDL approach, the study found that Bitcoin price volatility significantly affects Nigeria's exchange rate in both the short and long run. Specifically, in the long run, higher Bitcoin volatility contributes to an appreciation of the domestic currency, whereas in periods of low Bitcoin prices, increased demand for U.S. dollars to purchase Bitcoin leads to currency depreciation. Fakunmoju et al (2022), on the other hand examined the effect of cryptocurrency trading and corruption on economic performance in Nigeria using Tobit regression based primary data. Their findings reveal cryptocurrency and corruption exert a negative effect on Nigeria's economic performance. Similarly, Olorundare, et al., (2023) examined the prospects of cryptocurrency, its economic implications and public perception of regulation in Nigeria using primary data. Their findings revealed that 91% of respondents possessed knowledge of cryptocurrency, while 46.8% supported regulated cryptocurrency activities by the government as opposed to a total ban. Furthermore, 73% opposed restrictions preventing commercial banks from engaging in cryptocurrency transactions. The study highlighted that the growth of the Nigerian cryptocurrency market has been partly driven by the devaluation of the naira, which encourages individuals to explore digital assets as alternative stores of value.

Oladipupo et al., (2023) examined the economic and trade consequences of Nigeria's cryptocurrency prohibition. They assessed how crypto ban shaped domestic economic activities and cross-border trade. Using a mixed method of qualitative and quantitative technique, their result showed the ban on crypto transactions substantially reduced official cryptocurrency trading volumes which caused moving to informal peer-to-peer (P2P) networks. Furthermore, the move constrained innovation and undermined financial inclusion which negatively affected small and medium-sized enterprises (SMEs) that rely on cryptocurrencies for cross-border transactions. Ajibola et al., (2024) studied the impact of digital

currency on Nigerian economic growth utilizing average annual value of Bitcoin and Binance coin against gross domestic product from 2014 to 2023. Using a panel regression analysis, they found that there was no significant impact of cryptocurrencies on economic growth. This study failed to account for the high frequency nature of Bitcoin and other time series properties. Suleiman and Abdullahi (2024) investigated the influence of cryptocurrency on Nigeria's economic development, illicit financial flows, terrorism, and tax revenue. Estimating a multiple linear regression model, their result revealed a weak positive correlation between cryptocurrency and economic development showing that cryptocurrency transactions have no significant impact on Nigeria's economic development.

Lukianchuk et al., (2017) analyzed current trends, concerns, and unique aspects of cryptocurrency turnover with an emphasis on its implications for economic development, crime, and regulation in Ukraine. Their results indicate that cryptocurrency enhances economic growth through technological innovation. It equally found that cryptocurrency can facilitate cross-border crime in the absence of strong legal frameworks.

Tomic et al., (2020) investigated the potential effects of cryptocurrencies on the conduct and effectiveness of monetary policy by central banks in emerging markets. The findings indicate that cryptocurrencies reduce the effectiveness of traditional monetary policy tools by operating outside central bank regulation. This effect is amplified in countries with underdeveloped financial infrastructure which causes economic instability.

Bas et al., (2023) investigated the relationship between Bitcoin trading activity and traditional bank term deposits in the MINT countries—Mexico, Indonesia, Nigeria, and Turkey. Using country-level data spanning from the mid-2010s to the early 2020s, they employed panel data models, including cointegration and causality tests to examine the long-run linkages and direction of influence between Bitcoin trading volumes and bank deposits. The findings revealed a significant negative association between Bitcoin trading volumes and term deposit volumes in Indonesia, Nigeria, and Turkey, while no such effect was observed in Mexico. Ahmed (2024) investigated the role of Shariah-compliant security tokens in advancing financial inclusion within Islamic finance systems. The study was motivated by the question of how blockchain-based Islamic-compliant tokens and their associated technological and regulatory ecosystems can enhance access to finance, particularly for small and medium-sized enterprises (SMEs) in Muslim-majority regions. The findings revealed that Shariah-compliant security tokens offer alternative financing opportunities for SMEs that are often excluded from conventional financial channels. By leveraging blockchain ecosystems, these tokens provide enhanced transparency, stronger governance, and adherence to Islamic ethical standards.

Obisesan et al (2024) investigated the impact of cryptocurrencies on the economic growth of African countries with the aim of determining the extent to which Bitcoin, Ethereum, and Binance Coin affect economic growth. Using panel data from five African countries spanning 2016 to 2021, the study estimated OLS, fixed effects, and random effects models. They found that Bitcoin and Binance Coin exhibited a significant negative effect on GDP growth while Ethereum showed a significant positive impact on GDP growth. Their results suggest that some cryptocurrencies may constrain growth while others may enhance it. Sadiq et al (2023) conducted an empirical investigation into the role of digital currency and blockchain security in accelerating financial stability, with a particular emphasis on the mediating role of credit supply using data from financial institutions and digital currency markets.

Using regression-based mediation analysis, the study found that digital currency and blockchain security positively enhance financial stability. Credit supply was found to play a significant mediating role, as blockchain and digital currencies improve credit availability which in turn fosters greater stability in the financial system. Their findings emphasize that the impact of blockchain and digital currencies cannot be fully understood without considering credit supply mechanisms.

Wang et al (2024) explored the behavioral dimensions of cryptocurrency markets by examining the relationship between investor sentiment and price co-movement. They investigated how the widely used crypto fear-greed index influences price synchronicity across Bitcoin, Ethereum, Litecoin and Monero. The study utilized high-frequency intraday data to compute realized correlations to capture synchronicity in price movements. Employing statistical modeling, they established a nonlinear U-shaped functional relationship between sentiment and price synchronicity. Specifically, they found that both extremes of investor sentiment of excessive fear or heightened greed significantly increase the synchronicity of cryptocurrency prices. Conversely, moderate sentiment levels were associated with lower co-movements across the sampled assets. This implies that investor emotions exert a nonlinear influence on cryptocurrency market dynamics.

Panigrahi (2023) examined the nexus between cryptocurrency investments, financial stability, and economic growth in India using quarterly time-series data spanning 2015Q1–2022Q4. The study incorporated variables such as Bitcoin prices, financial stability index, inflation rate, real GDP, exchange rate, economic volatility uncertainty, and market volatility index. They estimated FMOLS and CCR to ascertain the long-run relationships between cryptocurrency adoption and macro-financial indicators. The results revealed an increase in cryptocurrency investments reduces financial stability. This implies that cryptocurrency adoption destabilizes the Indian financial system. El Hajj and Farran (2024) investigated the role of cryptocurrencies in fostering inclusive finance and economic empowerment in developing economies. The central question addressed was how cryptocurrency adoption influences financial inclusion among marginalized and unbanked populations in countries where cryptocurrency adoption has surged despite weak financial infrastructure. The findings revealed that cryptocurrencies significantly improve access to affordable financial services, lowering transaction and remittance costs while empowering marginalized groups through broader participation in the digital economy and cross-border trade.

3. Research Methodology

3.1. The Model

The model adopted for this study is a modified version of Asimakopolous et al., (2023) where the cryptocurrency sector was incorporated into a DSGE model of Nigerian economy. The current study departed from Asimakopolous et al., (2023) in the selection of prior distributions for Bayesian estimation to reflect the model economic peculiarity and the abstraction from cryptocurrency entrepreneurship productivity because Nigeria has not produced cryptocurrencies prior to this study. The model economy is populated by four agents, the households, the intermediate goods producing firm, the final goods producing firm and monetary authority.

Households

The problem of the representative household of the model economy is to maximize expected utility of the form

$$\max_{\{C_t, H_t, B_t, M_t^g, M_t^c\}} E\sum_{t=0}^{\infty} \beta^t A_t \left[u\left(C_t, \frac{\frac{M_t^g}{P_t}}{E_t^g}, \frac{\frac{M_t^c}{P_t}}{E_t^c} \right) - \eta H_t \right] \quad (1)$$

subject to the following budget constraint

$$M_{t-1}^g + \chi_t M_{t-1}^c + T_t + B_{t-1} + W_t H_t + D_t = P_t C_t + \frac{B_t}{R_t} + M_t^g + \chi_t M_t^c \quad (2)$$

Where β lie between zero and one, η is strictly positive. $\frac{M_t^g}{P_t}$ and $\frac{M_t^c}{P_t}$ are used to denote real balances of government currency and real balances of cryptocurrency respectively. χ_t is used to represent relative price of government currency against cryptocurrency given as $\chi_t = P_t / P_t^c$, where P_t^c denotes cryptocurrency price. According to equation (2), households' decision on consumption, real balance of government currency as well as real balance of cryptocurrency are joint decisions in the utility function. It is assumed that cryptocurrency represents a private digital currency serving as an alternative to government currency. This implies that household savings may be held in either commercial banks deposits or cryptocurrency holdings and household optimal choice of government currency and cryptocurrency holdings determines their marginal utility of consumption. From equations (1) and (2), C_t and H_t represents household period t consumption and labour supply respectively. The sources of income to the household in the budget constraint include T_t, nominal lump-sum government transfers, nominal dividend payments from firms in the intermediate goods-producing sector, D_t, value of nominal bonds from the previous period B_{t-1}, labour income $W_t H_t$ where W_t is the nominal wage. The households utilizes the income to fund consumption, C_t on finished goods at nominal price P_t, new bonds valued at $\frac{B_t}{R_t}$ where R_t is nominal interest rate. A_t, E_t^g and E_t^c are autoregressive shock processes on the IS curve, government currency and cryptocurrency demand curves respectively which are given as

$$\ln(A_t) = \rho^a \ln(A_{t-1}) + \varepsilon_t^a \quad (3)$$

$$\ln(E_t^g) = \rho^{\epsilon g} \ln(E_{t-1}^g) + \varepsilon_t^{\epsilon g} \quad (4)$$

$$\ln(E_t^c) = \rho^{\epsilon c} \ln(E_{t-1}^g) + \varepsilon_t^{\epsilon c} \quad (5)$$

Where $0 < \rho^a, \rho^{\epsilon g}, \rho^{\epsilon c} < 1$, ε_t^a, $\varepsilon_t^{\epsilon g}$ and $\varepsilon_t^{\epsilon c}$ are normally distributed innovations with standard deviations σ^a, $\sigma^{\epsilon g}$ and $\sigma^{\epsilon c}$ respectively.

Firms

The economy is populated by two types of firms, a continuum of monopolistically competitive firms indexed by $i \in [0,1]$ that produce differentiated varieties of intermediate goods and perfectly

competitive final goods producing firm that combines the varieties of intermediate goods for final production given the following constant-returns to scale technology

$$Y_t = \left[\int_0^1 Y_t(i) \frac{(\theta - 1)}{\theta} di \right]^{\frac{\theta}{(\theta-1)}} \quad (6)$$

Where $\theta > 1$. At each period, the final goods-producing firm combines $Y_t(i)$ amount of intermediate goods at the nominal price of $P_t(i)$ to manufacture $Y_t(i)$ units of final goods and maximizes profit by choosing

$$Y(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta} Y_t \quad (7)$$

This shows that θ measures the constant price elasticity of demand of each intermediate good. The zero profit equilibrium condition of the final goods-producing firm under perfect competition determines the price, P_t given

$$P_t = \left[\int_0^1 \left(P(i) \right)^{1-\theta} di \right]^{\frac{1}{(1-\theta)}} \quad (8)$$

A linear technology used by the representative intermediate goods-producing firm in each period to manufacture $Y_t(i)$ units of intermediate good i involves hiring $H_t(i)$ units of labour is given as

$$Y(i) = Z_t H_t(i) \quad (9)$$

Where Z_t represents aggregate productivity shock following the autoregressive process

$$\ln(Z_t) = \rho^z \ln(Z_{t-1}) + \varepsilon_t^z \quad (10)$$

Where $0 < \rho^z < 1$, ε_t^z is normally distributed innovations with standard deviations σ^z.

Monetary Policy

The nominal interest rate set by the monetary authority follow a modified Taylor rule as follows

$$\ln\left(\frac{R_t}{R} \right) = \rho^r \ln\left(\frac{R_{t-1}}{R} \right) + (1-\rho^r)\rho^y \ln\left(\frac{Y_t}{Y} \right) + (1-\rho^r)\rho^\pi \ln\left(\frac{\pi_t}{\pi} \right) + (1-\rho^r)\rho^{\mu^g} \ln\left(\frac{\mu_t^g}{\mu^g} \right) + \varepsilon_t^r \quad (11)$$

Where ρ^r denotes interest rate smoothing parameter, ρ^y coefficient on output, ρ^π coefficient on inflation, ρ^{μ^g} coefficient on government currency growth and $\mu_t^g = \left(M_t^g / P_t \right) / \left(M_{t-1}^g / P_{t-1} \right)$. ε_t^r is a normally distributed zero mean serially uncorrelated policy shock with σ^r standard deviation. Equation (11) shows the adjustment of short-term nominal interest rate in response to output and inflation deviations from their steady states levels.

Equilibrium

Following the computation of the first order conditions and Taylor approximation, the log-linearized equilibrium model follows Equations (12) to (16)

$$\hat{y}_t = \hat{y}_{t+1} - \alpha_1(\hat{r}_t - \hat{\pi}_{t+1}) + \alpha_2[(\hat{m}_t^g - \hat{e}_t^g) - (\hat{m}_{t+1}^g - \hat{e}_{t+1}^g)] + \alpha_3[(\hat{\chi}_t + \hat{m}_t^c - \hat{e}_t^c) - (\hat{\chi}_t + \hat{m}_{t+1}^c - \hat{e}_{t+1}^c)] + \alpha_1(\hat{b}_t - \hat{b}_{t+1}) \quad (12)$$

$$\hat{m}_t^g = \delta_1\hat{y}_t - \delta_2\hat{r}_t + \delta_3\hat{e}_t^g - \delta_4\hat{\chi}_t - \delta_4\hat{m}_t^c + \delta_4\hat{e}_t^c \quad (13)$$

$$\hat{m}_t^c = \delta_5\hat{y}_t - \delta_6\hat{r}_t + \delta_7\hat{e}_t^c - \delta_8\hat{m}_t^g + \delta_8\hat{e}_t^g \quad (14)$$

$$\hat{\pi}_t = \left(\frac{\pi}{R}\right)\hat{\pi}_{t+1} + \psi\left[\left(\frac{1}{\alpha_1}\right)\hat{y}_t - \left(\frac{\alpha_2}{\alpha_1}\right)(\hat{m}_t^g - \hat{e}_t^g) - \left(\frac{\alpha_3}{\alpha_1}\right)(\hat{\chi}_t + \hat{m}_t^c - \hat{e}_t^c) - \hat{z}_t\right] \quad (15)$$

$$\hat{r}_t = \rho^r\hat{r}_{t-1} + (1-\rho^r)\rho^y\hat{y}_t + (1-\rho^r)\rho^\pi\hat{\pi}_t + (1-\rho^r)\rho^{\mu^g}\hat{\mu}_t^g + \varepsilon_t^r \quad (16)$$

Equation (12) shows the log-linearized version of the consumption Euler equation linking the household's marginal rate of intertemporal substitution to real interest rate. A non-zero output elasticity to real balance of government currency, α_2 and output elasticity to real balance of cryptocurrency, α_3 shows the non-separability of consumption and real balances of government currency and cryptocurrency. This allows $\hat{m}_t^g$ and $\hat{m}_t^c$ terms to appear in the IS curve. Equation (13) represents government currency demand relationship incorporating income elasticity of government currency demand, δ_1,interest semi-elasticity of government currency demand, δ_2,elasticity of $\hat{m}_t^g$ with respect to government currency demand shock, δ_3 and cross elasticity of government currency demand and cryptocurrency demand, δ_4. Equation (14) represents cryptocurrency demand relationship incorporating income elasticity of cryptocurrency demand, δ_5,interest semi- elasticity, δ_6, elasticity of $\hat{m}_t^c$ with respect to crypto demand shock, δ_7,cross elasticity government currency demand. Equation (15) allows real balances of government and cryptocurrency to appear in the forward-looking Philips curve because of the non-separability in the utility function and thus directly influences marginal cost and inflation. Equation (16) represents the log-linear monetary policy rule. The relationship shows that interest rate adjusts to output, inflation and government currency growth.

3.2. Data Sources and Transformation

In this section, we explain the estimation procedures and sources of data. The evolution of cryptocurrency as a digital payment system is a very recent development which implies that studies involving cryptocurrency suffers from short data span. Modern cryptocurrency market development date back to 2008 (Nakamoto, 2008). In this study, we utilized monthly series from April 2013 to December 2024 (total of 141 months) in order to incorporate enough series to capture the dynamics of the model characteristics. Time series data for each of the shocks based on the theoretical model was used for estimation. Data on average monthly Bitcoin price sourced from (https://coinmarketcap.com) was used to proxy price of cryptocurrency because it is the most prominent cryptocurrency in terms of market capitalization, trading volume and global adoption (Chainalysis,2024). Total initial coin offering (ICO) sourced from (http://icodrops.com) was used to proxy cryptocurrency productivity by the

entrepreneurs. Although ICOs are not country-specific, it reflects the broader pace of innovations in the cryptocurrency ecosystem empirically used as a proxy for cryptocurrency productivity (Joshipura et al.,2025). We argue that Nigeria's exposure to global crypto transactions through fintech and digital transfer channels influence macroeconomic landscape in Nigeria. Macroeconomic series for model estimation were sourced from CBN statistical bulletin, namely: real private consumption expenditure, real broad money (M2), and monetary policy rate (MPR). The real gross domestic product (RGDP) was only available in quarterly form from 2013Q2 to 2024Q4. Thus, we transformed RGDP into monthly data series and seasonally adjust it using X-13 ARIMA-seats monthly seasonal adjustment method (U.S. Census Bureau, 2017). As its standard with DSGE models, the series were detrended using Hodrick-Prescott filter (Pfeifer,2014). Accordingly, we denote the detrended observed series and the associated exogenous shocks as shown in Table 1

Table 1 : Observed Variables and Exogenous Shocks

Acronym	Observed Variables	Shocks
op_t	Real GDP	productivity shock, eps_z
gc_t	Government (M2)	government currency demand shock, eps_eg
cp_t	Bitcoin price	cryptocurrency demand shock, eps_ec
pc_t	Real private consumption expenditure	preference shock, eps_a
ir_t	Monetary Policy Rate	monetary policy shock, eps_r

3.3. Model Parameter Selection

Tables 2 and 3 displays selection of prior mean for the endogenous parameters and parameters of the shock processes. Since our study is the foremost in incorporating the cryptocurrency sector in the DSGE model in Nigeria and given the paucity of empirical studies in this area, selection of suitable priors for model estimation constitutes a major contribution of this work. Unlike Asimakopolous et al., (2023), we allowed for non-informative prior means so that the data guides the prior mean choices and the resulting posterior mean based on Nigeria's macroeconomic environment. Following Asimakopolous et al., (2023), α_1 was fixed equal to one assuming the same level of risk aversion in the logarithmic consumption utility function in accordance with its consistency for monthly data frequency. For output elasticity to real balance of government currency α_2, we selected a normal prior mean to allow the data to determine the sign and magnitude of the resulting posterior mean in order to reflect the large informal sector and low monetary policy transmission in Nigeria (Bagudu & Okolie,2022; Ejinkonye,et al.,2023).. The prior mean of output elasticity to real balance of cryptocurrency α_3 follow a beta distribution to account for positive but limited use of cryptocurrency as a medium of transaction for real activities in Nigeria (Chainalysis,2024). Unlike Asimakopolous et al., (2023), we selected a small beta prior means for income elasticity of government currency demand δ_1, interest semi-elasticity of government currency demand δ_2, interest semi-elasticity of cryptocurrency demand δ_6, elasticity to real balance of government current with respect to government currency demand shock δ_3 while gamma prior mean was selected for income elasticity of cryptocurrency demand δ_5. The choice of these prior means reflects Nigeria's

empirical evidence of low sensitivity of money demand to interest rate changes but moderate-income elasticity which shows more cash preferences (Nakorji and Asuzu, 2019). Similarly, small income and interest elasticities to cryptocurrency demand reflect the understanding that crypto holdings are more responsive to speculation and remittance incentives than policy rate changes (Chainalysis,2024). Cross elasticities of government currency demand to crypto-demand δ_4 and crypto-demand to government currency demand δ_8 follow a beta prior distribution. This reflects the substitution effects between government currency and cryptocurrency. We selected moderate prior means for these cross elasticities given the high crypto adoption and strict regulation in Nigeria to reflect the potential for stronger substitution in a flexible regulatory environment. Elasticity of relative price of government currency to cryptocurrency ϱ, which governs the sensitivity of relative price of both currencies follow a gamma prior mean distribution. We selected a moderate prior mean to reflect uncertainties of exchange rate and price level changes in Nigeria. For the Taylor rule parameters, we selected beta prior mean for interest rate smoothing ρ^r, output coefficient ρ^y and government currency growth coefficient ρ^{μ^g}. Taylor rule coefficient on inflation ρ^π, follow a gamma distribution. The choice of high prior mean coefficient on inflation (1.98) reflects empirical evidence of stronger weight on inflation than output and interest rate in CBN reaction function. In general, we choose a wider prior standard deviation to accommodate extra uncertainty from other institutional volatility.

Table 2: Prior Selection of Endogenous Parameters

Parameter		Priors		
	symbol	Distribution	Mean	Std Dev.
Output elasticity to real bal. of govt. currency	α_2	Normal	0.047	0.0500
Output elasticity to real bal. of cryptocurrency	α_3	Beta	0.046	0.0100
Income elasticity of govt. currency demand	δ_1	Beta	0.056	0.0150
Interest semi-elasticity of the government. currency demand	δ_2	Beta	0.269	0.0500
Elasticity of real bal. of govt curr. to gov. curr demand shock	δ_3	Beta	0.553	0.1000
Cross elasticity of govt. curr. demand and crypto. demand	δ_4	Beta	0.397	0.0500
Income elasticity of cryptocurrency demand	δ_5	Gamma	0.060	0.0100
Interest semi- elasticity of cryptocurrency demand	δ_6	Beta	0.130	0.0500
Elasticity of real bal. of crypto. to crypto. demand shock	δ_7	Beta	0.801	0.1000
Cross elasticity of crypto. demand and govt. curr. demand	δ_8	Beta	0.710	0.1000
Elasticity of relative price btw govt. curr. wrt crypto.	ϱ	Gamma	0.655	0.1000
Interest rate smoothing	ρ^r	Beta	0.614	0.0500
Taylor rule coefficient on output	ρ^y	Beta	0.154	0.0100
Taylor rule coefficient on inflation	ρ^π	Gamma	1.980	0.0500
Taylor rule coefficient on govt. currency growth	ρ^{μ^g}	Beta	0.489	0.0500

We selected relatively high gamma prior mean for productivity shock persistence ρ^{z} along the line of Asimakopolous et al., (2023) assuming a more persistent technology shock than consumption preferences, government and cryptocurrency demand shocks. The moderate prior means for shock persistence to government currency demand, cryptocurrency demand and preferences follow a beta distribution. This was chosen to allow for Nigeria's macroeconomic uncertainties which also informed the selection of inverse gamma distribution with infinite prior variances of shock processes.

Table 3: Prior Selection of Shock Processes

Parameter		Priors		
	symbol	Distribution	Mean	Std Dev.
Productivity shock persistence	ρ^{z}	Gamma	0.921	0.0500
Government currency demand shock persistence	ρ^{g_E}	Beta	0.653	0.0500
Cryptocurrency demand shock persistence	ρ^{g_C}	Beta	0.774	0.0500
Preference shock persistence	ρ^{a}	Beta	0.706	0.0500
Productivity shock std. error	σ^{z}	Inverse gamma	0.070	Inf
Government currency demand shock std. error	σ^{g_E}	Inverse gamma	0.050	Inf
Cryptocurrency demand shock std. error	σ^{g_C}	Inverse gamma	0.010	Inf
Preference shock std. error	σ^{a}	Inverse gamma	0.030	Inf
Monetary Policy shock std. error	σ^{r}	Inverse gamma	0.076	Inf

Model Estimation Procedure

The Bayesian estimation method was deployed to estimate the posterior mean distribution of the parameters. As it is typical with Bayesian methodology, the posterior result is the outcome of the estimation using the prior mean selections. To implement the estimation, Markov Chain Monte Carlo (MCMC) method was applied with Metropolis-Hastings algorithm allowing for 50,000 posterior draws. Brooks and Gelman (1998) diagnostic test confirmed the moments of multiple chains. Based on the resulting posterior means, the Bayesian Impulse Response Function (IRF) of the model was plotted. In addition, the MCMC univariate and multivariate diagnostic tests as shown in Figures 6 were implemented to confirm model convergence.

4. Result

Tables 4 and 5 report the estimated posterior means and their respective 90 percent confidence intervals for the endogenous and exogenous parameters of the model. The estimated posterior mean of δ_1 is 0.0619. This captures income elasticity to government currency demand. The posterior mean is slightly higher than the prior mean value (0.056). This result suggests that government currency demand is not strongly driven by income. This is a reflection of the preference of cash-based transactions irrespective of level of income, financial exclusion and informal sector dominance (Bagudu & Okolie,2022; Ejinkonye,et al.,2023). The posterior mean of δ_2, interest semi-elasticity of government currency demand, is 0.067 which is much smaller than the prior mean of 0.269. This implies that government currency demand is weakly sensitive to interest rates adjustments. This is a reflection of low formal savings penetration and weak monetary policy transmission which limits interest rate channels in the financial system (Eleam, et. al., 2022). The posterior mean of δ_5 income elasticity of cryptocurrency

demand, shows that the posterior mean of 0.06 is equal to the prior mean. The alignment of the posterior mean with that the prior mean suggests that the demand for cryptocurrency is income sensitive. According to Chainalysis (2024), a greater percentage of cryptocurrency transactions are carried out by middle income earners who view cryptocurrency as a financial asset whose holding increases with increase in income for the purposes of remittances, savings and speculations. The posterior mean of interest semi-elasticity of cryptocurrency demand δ_6 0.13, matches the prior mean value. This suggests that cryptocurrency demand is moderately sensitive to interest rates. This shows that at the level of financial system development and regulation in Nigeria; cryptocurrency demand is not strongly responsive to domestic monetary policy rate (Vasylchyshyn, 2017;Alekseenko & Gidigbi ,2021). This further confirms the reason for the ineffectiveness of government ban in curbing cryptocurrency transactions in Nigeria. The ban led to the shifting to peer2peer transactions.

Table 4: Posterior of Endogenous Parameters

Parameter symbol				90% HPD Interval		
	Distribution	Prior Mean	Posterior Mean	Low	High	Std, Dev
α_2	Normal	0.047	0.0119	-0.0671	0.1010	0.0500
α_3	Beta	0.046	0.0476	0.0309	0.0633	0.0100
δ_1	Beta	0.056	0.0619	0.0364	0.0879	0.0150
δ_2	Beta	0.269	0.0669	0.0461	0.0873	0.0500
δ_3	Beta	0.553	0.6162	0.4692	0.7716	0.1000
δ_4	Beta	0.397	0.4506	0.3837	0.5283	0.0500
δ_5	Gamma	0.060	0.0600	0.0454	0.0733	0.0100
δ_6	Beta	0.130	0.1304	0.0906	0.1687	0.0500
δ_7	Beta	0.801	0.9645	0.9414	0.9891	0.1000
δ_8	Beta	0.710	0.6775	0.5086	0.8344	0.1000
ϱ	Gamma	0.655	0.6373	0.4825	0.7776	0.1000
ρ^r	Beta	0.614	0.6397	0.5942	0.6877	0.0500
ρ^y	Beta	0.154	0.1602	0.1424	0.1760	0.0100
ρ^π	Gamma	1.980	1.9442	1.8671	2.0319	0.0500
ρ^{ut}	Beta	0.489	0.4934	0.4083	0.5750	0.0500

The cross-elasticity parameters are used to capture currency substitution between government currency and cryptocurrency. δ_4 measures cross-elasticity of government currency demand to cryptocurrency demand while δ_8 measures cross-elasticity of cryptocurrency demand to government currency demand. The posterior means of δ_4 (0.4506) and δ_8 (0.6775) are close to their prior means of 0.397 and 0.710 respectively. This indicates moderate substitution between government currency and cryptocurrency in Nigeria. Despite regulatory barriers, high transactions in cryptocurrency shows that it serves as a partial substitute for naira especially under inflation and exchange rate pressures (Ajayi, 2022; Joseph, 2022). The slightly stronger

substitution of government currency demand to cryptocurrency demand aligns with the shifting to cryptocurrency by Nigerians as a hedge against naira depreciation (Ozili,2023). Elasticity of relative price between government currency and cryptocurrency ϱ, shows a close a posterior (0.6373) and prior (0.655) means. This supports a moderate sensitivity of currency choice to relative prices which implies that Nigerian crypto traders respond to movements in cryptocurrency prices. For the Taylor rule parameters, the interest rate smoothing ρ^{r} with a posterior mean of 0.6397, coefficient on output ρ^{y} of 0.16 and coefficient on inflation ρ^{π} of 1.944 are close to their respective prior means. The interest rate smoothing parameters confirms that there is significant smoothing in the data which shows CBN's cautious and gradual policy rate adjustments. This reflects central banks' preferences for making incremental changes to policy rates rather than abrupt, large adjustments to prevent excessive volatility in financial markets (Wieland & Sack,1999). The output response parameter (0.16) shows that CBN allocates lesser weight to output stabilization than price stability. This is reflected in the posterior mean of coefficient on inflation of 1.944. This is a confirmation that there is strong inflation targeting in Nigeria's monetary policy due to persistent high inflation (Lawrence,2023). The posterior mean of coefficient on government currency growth $\rho^{\Delta g}$ is 0.4934. This indicates a stable but partial response of CBN to monetary aggregates observed in the Nigerian monetary policy framework (Kumar, et al., 2013).

Table 5: Posterior of Shock Processes

Parameter	symbol	Posterior		
		Distribution	Mean	Confidence Interval
productivity shock persistence	ρ^{z}	Gamma	0.908	0.866 0.950
government curr. Demand shock persistence	ρ^{eg}	Beta	0.684	0.626 0.744
cryptocurrency demand shock persistence	ρ^{ec}	Beta	0.797	0.743 0.851
Preference shock persistence	ρ^{a}	Beta	0.781	0.733 0.827
productivity shock std. error	σ^{z}	Inverse gamma	0.282	0.253 0.310
government curr. demand shock std. error	σ^{eg}	Inverse gamma	0.053	0.037 0.069
cryptocurrency demand shock std. error	σ^{ec}	Inverse gamma	0.215	0.193 0.238
Preference shock std. error	σ^{a}	Inverse gamma	1.730	1.449 2.023
Monetary Policy shock std. error	σ^{r}	Inverse gamma	0.769	0.660 0.879

Impulse Response Functions

The impulse response functions (IRFs) generated based on the exogenous shocks to the estimated model and the response of the endogenous variables are reported in Figures 1 to 5. The shock processes are grouped into two traditional shocks which include preference (eps_a); productivity (eps_z); and monetary policy shock (eps_r); and currency demand shocks which include government currency demand (eps_eg) and cryptocurrency demand(eps_ec). The IRFs were generated based on respective means and standard errors of the shock processes for a 40 months horizon. Figure 1 reports the response of output, government currency, cryptocurrency, inflation and interest rate to consumer preference shock.

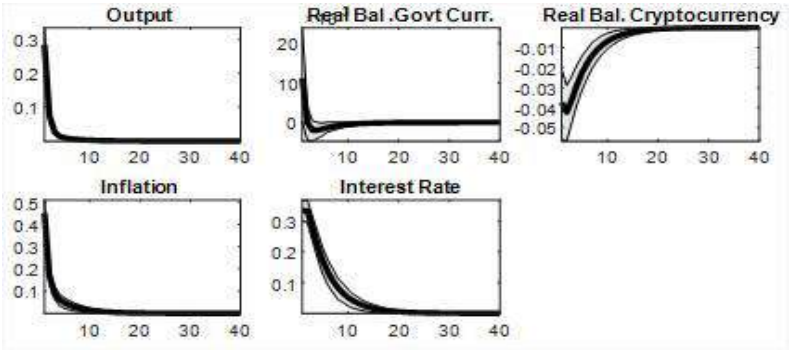


Figure 1: Preference shock - eps_a

Preferences indicate consumption and savings choices of households. Figure 1 shows that the households prefer consumption over savings. This causes output to increase on impact of the shock because increased consumer demand boosts economic activities which directly leads to GDP growth. As a result of the surge in consumption demand, production increases to meet the higher level of desired consumption leading to increased inflation. Expectedly, CBN responds by upward adjustment of interest rate to curb rising inflation to stabilize the economy. However, the preference shock leads to a fall in real naira balance as higher prices reduce the purchasing power of consumers leading them to access their cash savings to fund their rising consumption. Similarly, there is a fall in the real balance of cryptocurrency as people convert their cryptocurrency reserve to naira in order to finance their consumption which reduces their crypto balance. This shows that there is a substitution effect between naira demand and cryptocurrency demand for shock to preference. This finding is in line with Ireland (2004), Andres et al., (2009) and Asimakopoulos et al., (2023) whose findings showed a currency substitution effect as a result of increase in the relative prices of government currency with respect to cryptocurrency.

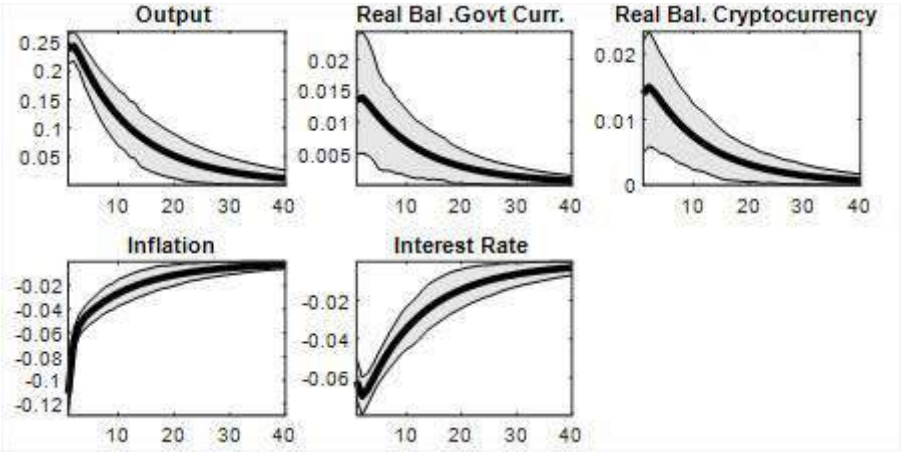


Figure 2: Productivity shock - eps_z

Figure 2 reports the response of output, government currency, cryptocurrency, inflation and interest rate to productivity shock which shows that a positive shock makes the economy more efficient due to technological improvement. Productivity shock on impact causes output to increase significantly and persistently. This implies that more goods and services can be produced using the same productive inputs as a result of improved production efficiency. Consequently, there is a fall in inflation as higher productivity causes a surge in supply of goods which pushes the price downwards. In order to maintain

productivity at its level, the CBN lowers interest rates to circumvent price pressures. Due to increase in output and low inflation, households hold more cash balances for consumption leading to increase in real balance of government currency. However, the rise in real balance of cryptocurrency suggests a wealth effect in the economy as overall increase in income due to productivity shock implies that households earn more which can be used to purchase crypto assets. This finding corroborates the finding of Ireland (2004) and Andres et al., (2009) which showed substitution effect because the relative price of government currency with respect to cryptocurrency increased.

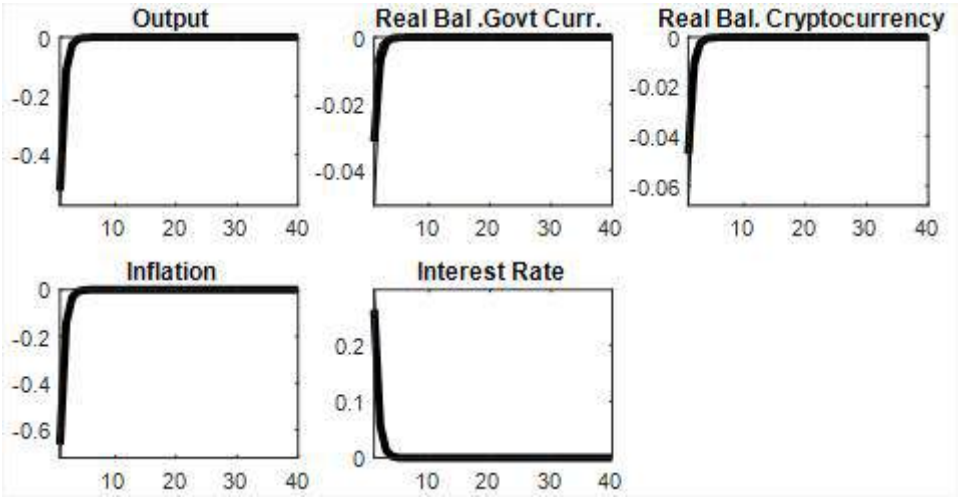


Figure 3: Monetary Policy shock - eps_r

Figure 3 reports the response of output, government currency, cryptocurrency, inflation and interest rate to monetary policy shock. As expected, a positive shock to interest rate causes output to fall on impact due to higher cost of borrowing which leads to reduced investment and consumption. This slows down economic growth. This confirms that CBN's aggressive monetary tightening to combat hyperinflation lowers growth. Due to the inflation targeting stance of CBN, the primary objective of monetary tightening is to fight inflation. Thus, rate hike induces a fall in aggregate demand leading to fall in the price level. The impact of interest rate hike on real balances of government currency and cryptocurrency follow a similar pattern due to the disinflationary effect of tightening. Due to economic contraction, both currencies fall with the effects being more pronounced in cryptocurrency as higher rates on naira savings makes it more attractive than the zero interest on cryptocurrency. This implies that there is a complementarity effect of monetary policy increase between cryptocurrency and the naira. This finding equally reveals the effectiveness of monetary policy in restoring confidence in the naira which mitigates capital flight into cryptocurrencies. Overall, monetary policy is effective in moderating the impact of cryptocurrency speculations on the economy. This finding supports Ireland (2004), Andres et al., (2009) and Asimakopoulos et al., (2023) who found currency substitution effect between government currency and cryptocurrency in a monetary policy tightening environment. However, it contradicts Bas et al., (2023) who found a significant negative association between Bitcoin trading volumes and term deposit volumes in Indonesia, Nigeria, and Turkey and Tomic et al., (2020) who found that cryptocurrencies reduce the effectiveness of traditional monetary policy tools by operating outside central bank regulation.

Considering the overall response to the traditional shocks, our finding indicates that there is substitutability of government currency and cryptocurrency for preference and productivity shocks. This implies that government currency and cryptocurrency react much the same way for a preference or productivity shock. This shows that cryptocurrency is not the main driver of other variables rather it

responds to movements in government currency balance. Contrarily, government currency and cryptocurrency react differently to a shock on monetary policy.

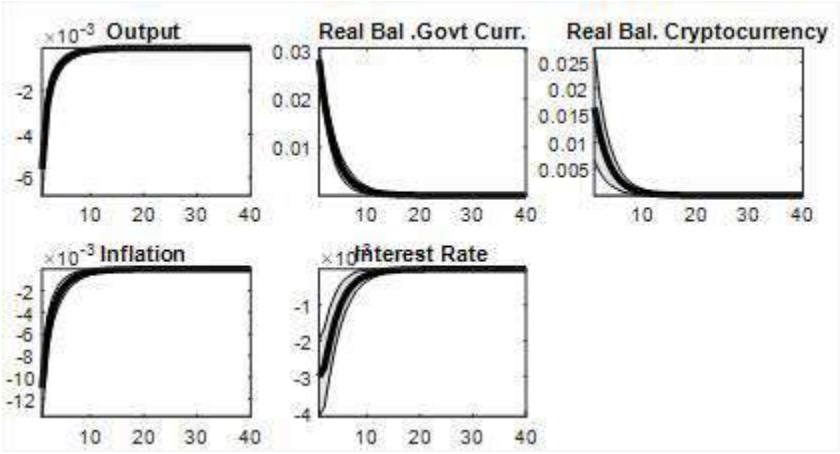


Figure 4: Government currency demand shock - eps_eg

Figure 4 reports the response of output, government currency, cryptocurrency, inflation and interest rate to government currency demand shock. This shock represents a sudden increase in people's preference to hold naira triggering liquidity hoarding. This shock on impact causes output to decline because holding more cash reduces spending on consumption and investment which in turn causes decline in aggregate demand and fall in output. Government currency demand shock induces a fall in inflation as the decline in aggregate demand for goods and services creates downward pressure on prices. The CBN reacts by lowering interest rates and making borrowing cheaper as a result of the falling output and prices in a bid to stimulate the economy. Real balance of cryptocurrency also falls indicating a substitution effect as people momentarily shifts from cryptocurrencies into naira as a safer asset. This flight to safety scenario is typical in the Nigerian economic context where incessant domestic banking sector stress, extreme volatility and fear of crypto market collapse pushes people to keep physical cash. It is expected that a cut in monetary policy rate should encourage people to spend the hoarded money.

Figure 5 reports the response of output, government currency, cryptocurrency, inflation and interest rate to cryptocurrency demand shock. This shock is important for monetary authorities because it is reflective of the scenario people move their wealth into cryptocurrencies in periods of hyperinflation and naira devaluation. Due to the impact of shock to real balance of cryptocurrencies, output falls following a diversion of funds from consumption and investment in the real economy into financial assets which in turn depresses aggregate demand leading to a fall in prices. Real balance of naira decreases as people are using naira to buy cryptocurrencies. This further confirms a substitution effect between naira and cryptocurrency. The capital flight induced by shift to cryptocurrency weakens the naira while the CBN reacts by lowering interest rate to counter negative output gap and disinflationary pressure. This finding is in line with Panigrahi (2023) who found that increase in cryptocurrency investments reduces financial stability in India. However, this finding counteracts Sadiq et al., (2023) who argued that digital currency and blockchain security positively enhance financial stability.

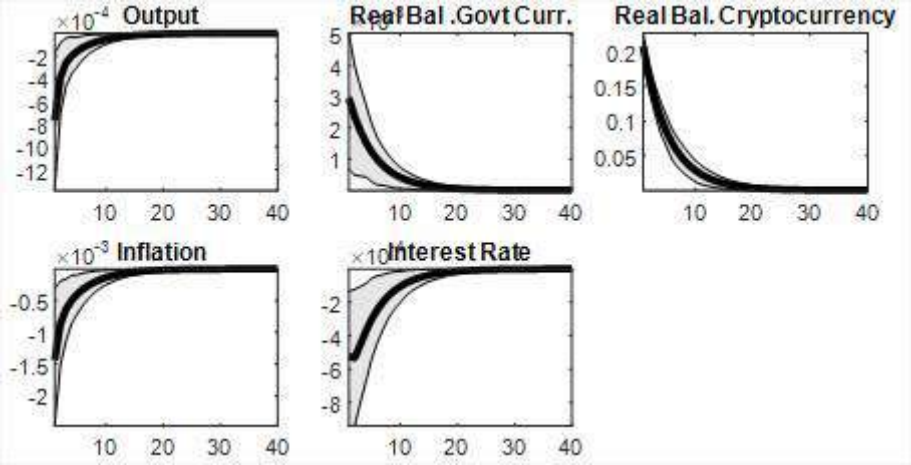


Figure 5: Cryptocurrency demand shock - eps_ec

Discussion of Findings

In this study, the cryptocurrency sector was integrated into a DSGE model of the Nigerian economy. The result of the DSGE model based on the Bayesian estimation framework yields a critical insight in understanding the interplay between cryptocurrency and government currency. The key finding of this study is the existence of a dual relationship between cryptocurrency and domestic currency. Cryptocurrency acts as a substitute to naira in response to real economic shocks (preference, productivity, and currency demand shocks) but exhibits complementarity in response to nominal monetary policy shocks. This finding has several implications on monetary policy and financial stability in Nigeria. Firstly, the finding of substitution effect when there is preference and productivity shocks is in line with empirical reality on the usage of cryptocurrency in Nigeria (Chainalysis, 2024). The adoption and usage of cryptocurrency is mainly dominated by the middle class with moderate holdings whose currency demand is majorly driven by potential short-term utility. Thus, when there is positive preference shock for consumption, people liquidate both naira and cryptocurrency savings to finance expenditure. This shows that, in the Nigerian context, both currencies are perceived as stores of value to be utilized for immediate spending. The finding also reveals moderate substitution effect in response to government currency demand shocks (flight to safety into naira) and cryptocurrency demand shocks (flight from naira into crypto). Due to domestic economic uncertainties, people tend to substitute between both currencies as potential hedge against high inflation and naira depreciation. This finding is supported by Ireland (2004), Andrés et al. (2009) and Nakorji & Asuzu (2019) who argued that concerns over banking sector stability and persistent currency depreciation remains a major driver of asset diversification. The finding is further validated by the moderate but significant cross-elasticity parameters. Despite regulatory barriers, cryptocurrency still serves as a partial substitute for the naira.

Secondly, the finding of currency complementarity between government currency and cryptocurrency in response to monetary policy shock in Nigeria is a critical departure from previous literature (Ireland, 2004; Asimakopoulos et al., 2023). This finding is critical given the concerns of monetary policy effectiveness in the face of alternative currency like the cryptocurrency. The finding reveals that there is a simultaneous decline in the real balances of both naira and cryptocurrency to a contractionary monetary policy shock. When the CBN raises the monetary policy rates with the aim of curbing inflation, peoples' confidence in naira is restored and naira-denominated savings become more attractive due to expected higher returns. As a result, capital flight into cryptocurrency is mitigated given the increased opportunity cost of holding zero-interest crypto assets. Thus, the finding confirms that a credible monetary policy can be an effective tool towards the management of capital flows

between the traditional financial system and evolving cryptocurrency market and further moderate the impact of cryptocurrency speculation on the economy (Ahmed & Ricardo, 2022). This demonstrates that the coexistence and complementarity of government currency and cryptocurrency in Nigeria have created a new dynamic in monetary policy response to shocks. Therefore, there is a need for regulatory frameworks to manage this dualism. However, the low interest semi-elasticity of government currency demand with a posterior mean of 0.067 shows that there is weak monetary policy transmission in the economy. This phenomenon was attributed to the existence of a large informal sector and low financial inclusion system (Eleam, et. al., 2022). Concurrently, the fact that cryptocurrency demand is moderately sensitive to income but not strongly responsive to the policy rate supports the understanding that crypto holdings are driven more by remittance, savings, and speculative motives than by cyclical interest rate adjustments (Chainalysis, 2022). This may explain the reason behind the failure of blunt instruments like the 2021 ban on cryptocurrency transactions in Nigerian banks which merely shifted transactions to peer-to-peer platforms rather than curbing demand.

Policy Implications

1. The findings of this study suggest a paradigm shift in the regulatory and monetary policy approach towards cryptocurrency in Nigeria. Empirical evidence showed that a blanket prohibition of crypto transactions without considering the underlying economic drivers has proven counterproductive. The persistent substitution effect implies that cryptocurrency demand is inelastic to outright suppression. Therefore, there is the need for monetary authorities to develop a robust regulatory framework instead of prohibition. There should be compulsory licensing for crypto exchanges with strong mechanisms against money laundry and clear taxation guidelines for crypto operators in Nigeria.

2. The finding that effective monetary policy induces complementarity between the naira and cryptocurrency implies that the current condition is not harmful to policy transmissions. There is a need for CBN to strengthen its inflation targeting credibility. This involves consistent and transparent communication together with improvement in the monetary policy transmission mechanism by deepening the financial system and increasing formal savings penetration. A credible policy regime reduces the desire to shift to cryptocurrency as a hedge against policy uncertainty and naira depreciation.

3. The finding of moderate substitution effects show that both currencies stand as alternatives for utility. This emphasizes that there is opportunity for the use of CBDC alongside the fiat currency. The CBN should make the naira more attractive by aggressively promoting its digital currency, the eNaira. This can be achieved by integrating it with innovative financial services and digital payment platforms. Thus, CBN can provide a digital payment alternative that meets public demand while retaining monetary sovereignty by offering a CBDC that is efficient, accessible, and trustworthy.

4. The concerns that the crypto market can trigger financial instability necessitate the need for the implementation of macroprudential surveillance in the crypto market. Monitoring activities in the crypto market can mitigate its spillover effects from crypto demand shocks to output, inflation and financial stability. The monetary authorities should evolve frameworks to monitor the size and interconnection of the crypto market with the traditional banking system. This will help in identifying and mitigating systemic risks that could arise from a sharp downturn in the crypto market.

Conclusion

This study investigated monetary transmission dynamics between cryptocurrency and the traditional fiat system in Nigeria. A cryptocurrency sector was incorporated into a DSGE model estimated through the Bayesian framework. The non-informative prior means were selected to reflect the data and economic structure in operation in Nigeria. A key finding from the analysis of this study is that the

relationship between the naira and cryptocurrency is not uniform but critically depends on the nature of the underlying economic shock. There is a substitution effect between the naira and cryptocurrency in response to real economic shocks. This is an indication of the role of cryptocurrency as a hedge and alternative store of value during periods of domestic economic uncertainty. Contrarily, there is a complementarity effect between the naira and cryptocurrency in response to a monetary policy shock, where a credible tightening by the CBN restores confidence in the naira and dampens capital flight into crypto assets. Given the persistent substitution effect despite the restrictive regulatory environment, we conclude that the demand for cryptocurrency in Nigeria is structurally embedded and driven by deep-seated factors such as inflation hedging, remittance needs, and a lack of confidence in the traditional financial system. Again, the evidence of complementarity during monetary policy tightening reveals that a credible and well-communicated inflation-targeting regime can be effective in managing the crypto-fiat dynamics which mitigates its potential destabilizing effects.

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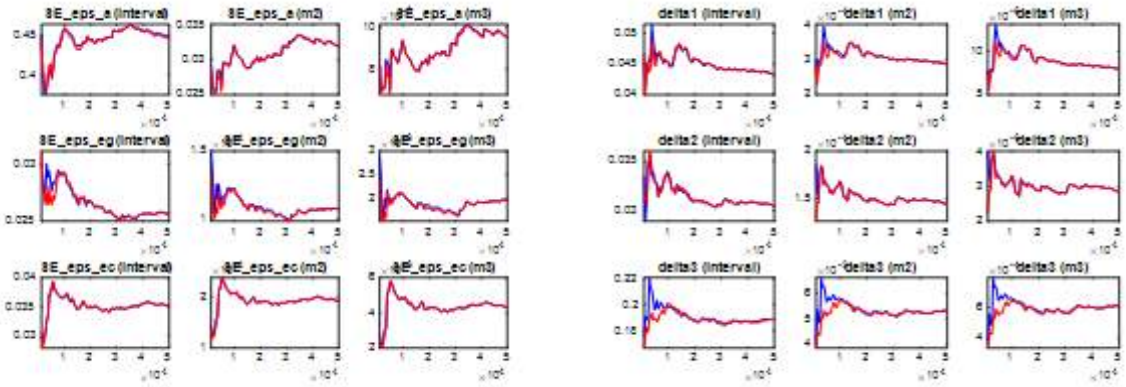
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Appendix.

Convergence Diagnostics



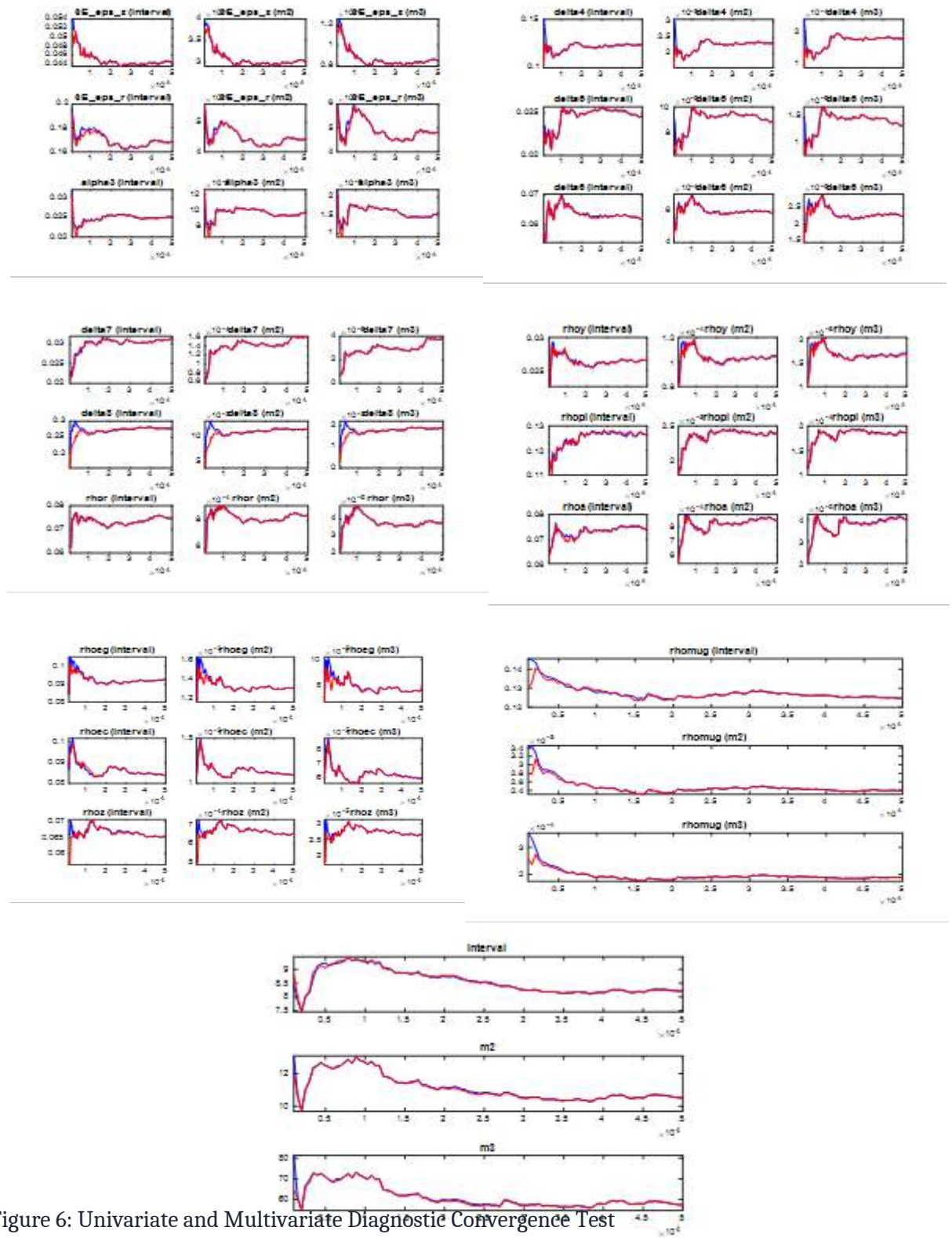


Figure 6: Univariate and Multivariate Diagnostic Convergence Test

Prior and Posterior Plots

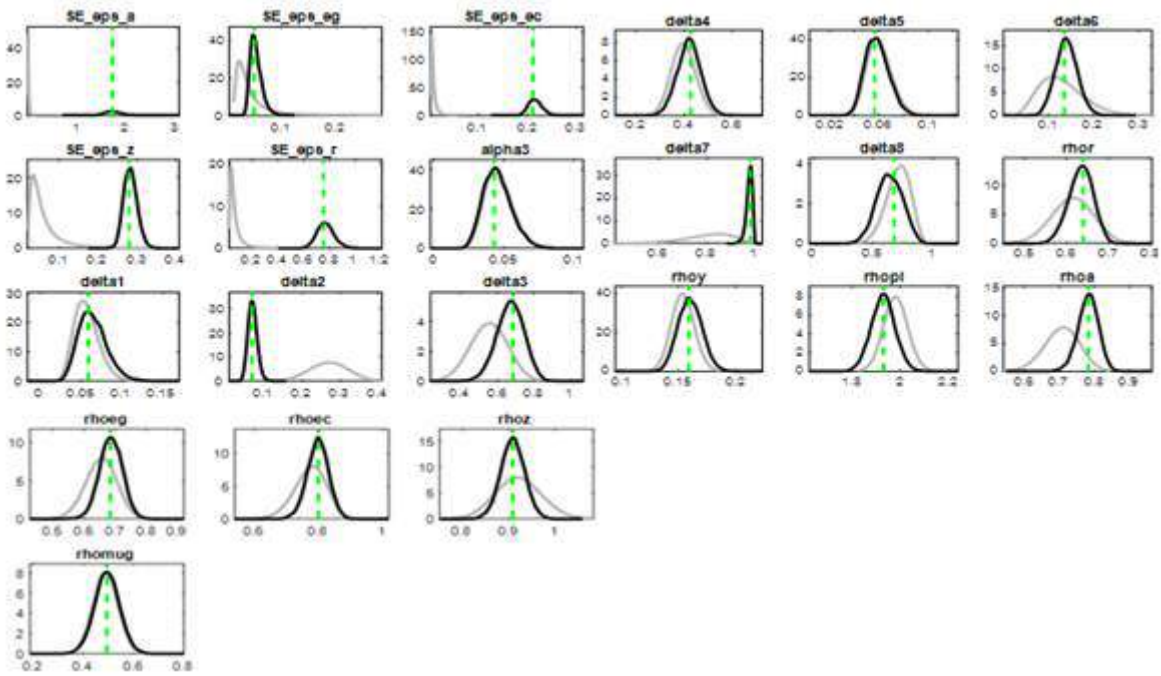


Figure 7: Prior and Posterior Mean of Parameters Plots

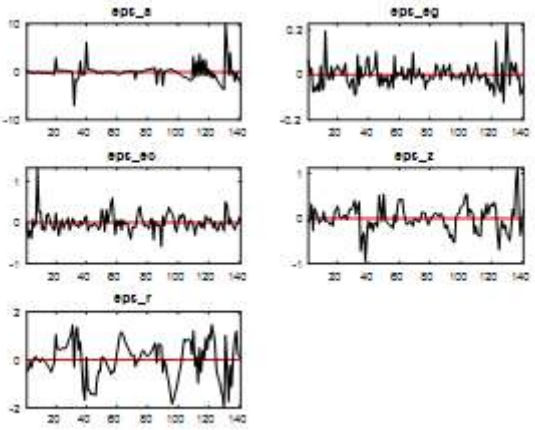


Figure 8: Smoothed Shocks

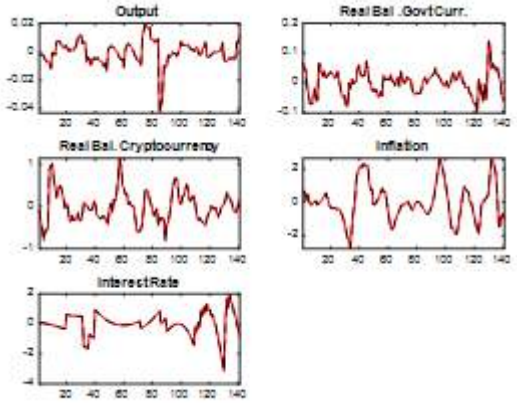


Figure 9: Historical and Smoothed Variables

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Gross Domestic Product Growth and External Debt Stock Nexus in Nigeria, 2000–2023: A Granger Causality Investigation

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ABSTRACT

This paper is an appraisal of the causal effect between gross domestic product growth rate and that of external debt stock of Nigeria for the period 2000 – 2023. Foreign borrowing in Nigeria seems to have become a recurring phenomenon in spite of the growth in the country's Gross Domestic Product. The questions in this study tend to establish the causality between the different components of the country's GDP and the country's mounting External Debt Stock. The time series used in the analyses were tested for stationarity adopting the Augmented Dickey Fuller Unit Root test. They were found to be stationary at levels except growth rate of government savings which was stationary at first differencing necessitating the use of Autoregressive Distributed Lag (ARDL) Bounds test econometric technique to unravel if any cointegration of the variables exists in the long run. The results showed no existence of cointegration in the long run. The Granger Causality test unveiled a bidirectional causality from rate of government final consumption expenditure to external debt stock and vice versa. No other explanatory variable has significant causality effect with REXDS. There is a unidirectional causal link between Government savings rate (GRGS) and rate of import (RIMPT) in Nigeria. The causality runs from GRGS to RIMPT. No significant causal effect was discovered between rate of external debt stock and other explanatory variables. The study recommends among others that the government should consider a decrease in government final consumption expenditure a necessary option for the mitigation of persistent foreign borrowing in Nigeria.

Keywords: **Export, government Final Consumption Expenditure, Government Savings, External Debt Stock, Import, Gross Domestic Product**

Introduction

When tax revenue of an economy falls below government's proposed expenditure, debt finance becomes an important instrument at the disposal of the government to achieve the estimate. Borrowing in this way can be from internal or external sources. An intended external debtor country is expected to consider its worth in the international market - the rate of growth of its gross domestic product to be able to borrow a certain amount of money. Developing countries such as Nigeria have had a time when they could no longer contain their external debt stock and pleaded for debt relief which came about in 2006. Little after this in 2010, the country's external debt stock started mounting up again to the tone of US$8.4 billion in spite of the fact the rate of growth of the country's GDP for that period was as high as 8.01%. In the year 2015 when the real GDP fell to 2.7%, Nigeria's external debt stock rose to US$35.5 billion. As the real GDP came to -1.79% in 2020, there was an up-thrust of the country's external debt stock to US$87.65 billion. As the GDP growth rate marginally improved to become 2.86 in 2023, the foreign borrowing rose to a jumbo sum of US$102.48 billion (Macrotrends, 2025). To empirically unravel the above scenario where the external debt stock keeps rising without reference to the performance of the rate of GDP should preoccupy the minds of economic analysts.

Statement of the Problem

If external Debt is not properly managed, it can reduce investors' confidence and

negatively impact even economic growth. The burden of its servicing forms a serious dent on the foreign reserve of the debtor country. It can make a country vulnerable to adverse global market conditions and sends a deterrent signal to intending foreign investors especially if the debt stock is large. Countries with large stocks of external debt suffer a debt crisis if the growth of the gross domestic product is low. Responding to economic shocks in a country will be difficult with a high rate of growth of external borrowing. This is so especially if the foreign debt is dominated in the currency of the creditor country. This is the worst in the era of floating exchange rate.

Objectives of the Study

This study is mainly to unravel the causal effect between growth rate of the gross domestic product of Nigeria and the stock of its external indebtedness. The specific objectives are:

1. To examine the causal effect between rate of government final consumption expenditure in Nigeria and its stock of external borrowing

2. To establish the causality effect between rate of government savings and foreign debt burden of the country

3. To unveil how the rate of export is linked with rate of foreign borrowing in Nigeria

4. To investigate the causal association between rate of import in Nigeria and its external debt stock.

Research Questions

The questions to be addressed by this study are:

1. What is the causality effect between the rate of government final consumption expenditure in Nigeria and its rate of external debt stock?

2. What is the causality between government savings and foreign debt burden in Nigeria?

3. How is the rate of exports in Nigeria causally related to the rate of external indebtedness in Nigeria?

4. What is the causality effect between rate of import and foreign debt stock in Nigeria?

Research Hypotheses

The hypotheses to be tested in this study are:

HO_1: The causality effect of government final consumption expenditure on external debt stock in Nigeria is not significant.

HO_2: There is no causality relationship between government savings and foreign debt stock in Nigeria.

HO_3: The link between rate of export in Nigeria and burden of foreign borrowing is not significant.

HO_4: No causality exists between rate of import in Nigeria and its external debt stock.

Significance of the Study

The knowledge from the study will guide policymakers to make rational decisions about foreign borrowing and the servicing of the debt. It will enable them to design effective fiscal policies that will balance the economic growth objective of an economy with debt sustainability especially in developing countries. Investors (foreign and local) will be guided in their investment decisions as the study is a type of assessment of risks associated with high external debt burden.

Scope and limitation of the Study

The study is an investigation of the causality effect between rate of growth of gross domestic product and external debt stock of Nigeria for the period 2000 – 2023. The choice of this period is justified by the existence of prolonged democratic rule in the country. However, the study is limited by sample bias, scarcity and quality of data.

Review of related Literature

Gross domestic product growth is the performance rate of an economy's total value of goods and services produced within a specific period of time usually quarterly or annually. It is one of the indicators of an economy's development. An abysmal performance of an economy's gross domestic product is an unacceptable signal indicating a possible negative balance of payment for the economy. This situation may end up in foreign borrowing. The external borrowing when it accumulates, becomes an external debt stock which according to the United Nation (2020), is the portion of a country's debt from foreign creditors that include governments and international financial institutions. Normally, the debt and interest on the loan are repaid in the currency of the creditor. To earn the currency of the creditor country, the debtor country is expected to increase its exports of goods and services to that economy. Governments often borrow locally or internationally when a country's balance of payment (BOP) is in deficit. One of the reasons for the closing of the gap in BOP is for the government to be able to spend on its final consumption. The World Bank (2025) refers to government final consumption expenditure as all the government's current expenditure on goods and services. It excludes government military expenditure as it forms part of government capital formation spending. When the BOP of a country is in surplus, there is the tendency for the government to save part of the income. Mankiwi (2011) defined Government savings as the total of a country's income from tax minus public expenditures. Ideally, it is income set aside for future use. The two components of international trade viz; export and import can also result in surplus or deficit BOP. The export referred to as goods and services produced in a country and sold to buyers in another country (Troy, July 13, 2025) is a source of revenue to the producing country. The higher the rate of a country's export, ceteris paribus, the higher is the revenue from the sale. Conversely, import has been defined as goods and services purchased by a country other than the producing country (Troy, Sept. 27, 2025). High rates of import can diminish a country's revenue and negatively impact the country's balance of payment. This often results in further borrowing to remedy the situation. To examine the external debt stock nexus with economic growth, debt overhang theory explains that high external debt can hamper the effectiveness of government's savings and investment as the debt is bound to be serviced. External debt servicing takes a significant portion of government savings, reduces government final consumption expenditure and limits investment with its attendant negative impact on the rate of growth of the gross domestic product of the indebted country (Sami, 2025).

There are many empirical investigations by scholars aimed at unraveling the association of external debt stock with the growth rate of gross domestic product of countries. For instance, government expenditure and total public debt in Nigeria was found to be positively related using Error Correction technique (Oligbi, 2024). This study showed no dichotomy between domestic and external debt. Oyedokun (2023), using Auto-regression distributed Lag in the study of external borrowing, government expenditure and road construction in Nigeria unveiled a significant and indirect long run relationship between government expenditure a4nd external debt stock. The study revealed that a 1% increase in external debt stock and interest payment will decrease government expenditure by 0.26% and 12.3% respectively. In Kakeeto (2018) that used vector Autoregressive model and granger causality approach to ascertain the relationship between External Debt Stock and government final consumption expenditure, external debt stock was revealed to have a positive and unidirectional causal association with government final consumption expenditure. This relationship was found to run from government final consumption expenditure to external debt stock. In the study, a unit increase in government final consumption expenditure was discovered to effect a 57.2 percent increase in external debt stock in the short run. This finding negates that of Adamgbo and Okowa (2025) in modeling the impact of External Debt Stock and Servicing on Export in Nigeria, 1981 – 2010 using Correlation statistical technique. The result showed a negative correlation between the variables in the case of Nigeria. Mamum and Khan (2020) in testing the long run empirical relationship between debt and imports with evidence from Bangladesh, used Granger Causality based vector error correction technique to discover a significant unidirectional causality running from debt to import in the long run. However, in the short run, a unidirectional causality that runs from import to debt was unraveled. This indicates that Bangladesh debt causes import in the long run while in the short run, the effect of import on debt was inconsequential.

The reviewed studies tend to explain the link between one indicator of gross domestic product or the other and external debt stock in Nigeria. However, this study examines the causality between the indicators of GDP and Nigeria's external debt stock. The result of the study will foster more understanding of the major area(s) of the association between GDP and external debt stock.

Methodology

The study adopted ex-post-facto research design to elicit the direction of the causality between the variables under consideration. Time series data used are from the Central Bank of Nigeria Statistical Bulletin for the year 2024. The bulletin is a veritable source of secondary data for macroeconomic indicators in Nigeria. Because of the spurious results that the use of time series data present in analysis, this study employed a unit root test of Augmented Dickey Fuller technique to ascertain the stationarity of the data.

Model Specification

The model specified for investigation followed the empirical study of Kakeeto (2018) which specified gross domestic product as a function of the different components of external debt stock and used Ordinary Least Square technique to unravel the relationship between the dependent and independent variables. However this study has modified the Kakeeto (2018) model by introducing the growth rates of the components of gross domestic product as determinants of the rate of growth in foreign borrowing by Nigeria and will use Autoregressive Distributed Lag Bounds test to unravel if any long run cointegration exists between the dependent and explanatory variables. Granger Causality test will be adopted to unveil the synergy between the variables. The independent variables are: rate of government

final consumption expenditure, rate of government savings, growth rate of exports and rate of imports. The relationship is stated in implicit functional form as:

REXDS = f(RGFCE, GRGS, REXP, RIMPT).....(1)

Where:

EXDS = External Debt Stock growth rate

GRGS = Government Savings growth rate

REXP = Export growth rate

RIMPT = Import growth rate

The equation (1) is explicitly stated as in the below:

$REXDS_t = a_0 + a_1RGFCE_t + a_2GRGS_t + a_3REXP_t + a_4RIMPT_t + u_t$.....(2)

Where: a_0 is the intercept, a_1 - a_4 are the parameters of the model to be estimated. The stochastic error term is represented by u_t. It is a priori expected that the rate of government savings and export be negatively signed while rates of import and government final consumption expenditure be positively signed.

Data Analysis

The results of the Augmented Dickey Fuller Unit Root Test are given below.

Table 1: Augmented Dickey Fuller Unit Root Test

Variable	t-Statistic	5% critical value	Order of integration
REXDS	4.578176	3.259808	1(0)
GRGS	4.321237	1.982344	1(1)
REXP	4.816748	3.175352	1(0)
RGFCE	4.790554	3.259808	1(0)
RIMPT	4.845197	3.212696	1(0)

Source: Computer output Eviews version 9

Information in the above table shows that the time series for the variables have a mixed order of integration. While other variables are stationary at level, the growth rate of government savings is stationary at first differencing. There is no second order of integration hence, the relationship between the variables is tested using autoregressive distributed lag bounds test the results of which are in the table 2 below.

Table 2: ARDL Bounds test Results

Null Hypothesis: No long-run relationships exist

Test Statistic	Value	k
F-statistic	1.345248	4
Critical Value Bounds		

Significance	I0 Bound	I1 Bound
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Source: Computer computation from E-views version 9

From the above table, F-Statistic value is 1.345248 which is less than the lower bound critical value at 5% level of confidence. The result shows that no long run relationship exists between external debt stock and GDP in Nigeria within the study period hence, the test for granger causality.

Pairwise Granger Causality Tests
Date: 11/12/25 Time: 03:22
Sample: 1 17
Lags: 2

Null Hypothesis:	Obs	F-Statistic	.+ Prob.
GRGS does not Granger Cause REXDS	10	0.73707	0.5242
REXDS does not Granger Cause GRGS		4.19637	0.0852
REXP does not Granger Cause REXDS	10	0.55333	0.6066
REXDS does not Granger Cause REXP		0.88177	0.4699
RGFCE does not Granger Cause REXDS	10	10.2327	0.0171
REXDS does not Granger Cause RGFCE		7.45509	0.0316
RIMPT does not Granger Cause REXDS	10	0.14851	0.8657
REXDS does not Granger Cause RIMPT		3.11088	0.1325
REXP does not Granger Cause GRGS	10	0.27334	0.7715
GRGS does not Granger Cause REXP		0.25018	0.7879
RGFCE does not Granger Cause GRGS	10	3.94848	0.0936
GRGS does not Granger Cause RGFCE		4.58603	0.0739
RIMPT does not Granger Cause GRGS	10	3.28654	0.1227
GRGS does not Granger Cause RIMPT		9.27295	0.0208
RGFCE does not Granger Cause REXP	10	0.20873	0.8183
REXP does not Granger Cause RGFCE		0.49435	0.6369
RIMPT does not Granger Cause REXP	10	1.03995	0.4191
REXP does not Granger Cause RIMPT		2.38925	0.1870
RIMPT does not Granger Cause RGFCE	10	0.17793	0.8421

RGFCE does not Granger Cause RIMPT	0.33579	0.7297

Source: Computer output Eviews version 9

Discussion of findings

According to the unit root test, the time series used have a mixed order of integration at levels 1(0) and first differencing 1(1). This called for an Autoregressive Distributed Lag test to unravel the long run cointegration of the variables. The ARDL Bounds test showed no cointegration of the variables. The F-Statistic (1.345248) was less than the lower bound critical value at 5% level of confidence. This indicates that there is no long run relationship between external debt stock and the dependent variables in Nigeria. The null hypothesis is accepted and the alternative of presence of long run cointegration rejected. However, the investigation is meant to unravel granger causality and the direction.

The Pairwise Granger Causality Test result unveils spectacular results for Nigeria. There are positive bi-directional causality between growth rate of government final consumption expenditure and rate of external debt stock. The implication of this is that for the Nigerian government to increase its final consumption expenditure by one percent, it must increase its foreign borrowing by 10.23% thereby making the economy dependent on foreign debt. This explains why the external debt of the country is mounting upward. On the other hand, a one percent increase in this external borrowing causes an increase in government consumption expenditure by about 7.46%. This translates to 75 percent of what is

borrowed externally being spent on the government's purchase of goods and services. The bi-directional causality is both positive and significant. Other explanatory variables have no causality effect on the rate of external debt stock in Nigeria.

Growth rate of government savings is shown to have a unidirectional causality with growth rate of import in Nigeria. This association is also both positive and significant. An increase in government savings by one percent is discovered to increase the rate of government's importation of goods and services by 9.27%. Speaking economics, an increase in savings is expected to increase investment. For Nigeria, when the government saves, it is meant for importation of goods and services. This equally explains why the abysmal performance of the manufacturing sector in the country. That about 93 percent of the country's Balance of Payment surplus being used for importation of goods and services contradicts the economic theory which stipulates that increase in savings leads to increase in investment. However, the rate of import does not granger cause growth in government savings. Consequently, it could be said that the mounting external debt stock in Nigeria is fueled by the growing rate of government final consumption expenditure thereby making the country more of a consuming economy.

Conclusion and Recommendation

After the external debt relief of 2006, Nigeria started accumulating another stock of foreign debt. The study is an investigation of the causality effect between the external debt stock of the country and the components of the country's gross domestic product to understand the aspect of the GDP that has a direct impact on the external debt stock of the country. The econometric analysis that adopted the ARDL bounds test after ascertaining the stationarity of the time series used, has unveiled no long run cointegration between the external debt stock of Nigeria and the different components of the GDP. Further investigation using Granger causality test reveals a positive and significant bidirectional causality between rate of government final consumption expenditure and external debt stock in Nigeria.

It also indicated a unidirectional positive causality that runs from growth rate of government savings to rate of import of goods and services in Nigeria.

Recommendations

Given the impressive results of the study analyses, this study recommends for policy implication as follows:

1. The government should devise means of reducing its final consumption expenditure so as to reduce its external debt stock.

2. Part of what is saved by the government through Balance of Payment surplus should be invested. It should reduce its importation of goods and services.

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Fiscal Policy and Low Carbon Investment: A Sub-Saharan African Country Analysis

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ABSTRACT

Sub-Saharan African countries remain deeply anchored in fossil-fuel-dependent energy systems, and this results in a development trajectory that is increasingly carbon-intensive and vulnerable to environmental decline and external energy price volatility. Fiscal policy is yet to be harmonized with green initiatives, even with the growing need to finance low-carbon development towards achieving sustainable development. This creates the need to examine how fiscal policy can help to stimulate low-carbon investment across Saharan African (SSA) countries. Therefore, the objective of this paper investigate how fiscal policy instruments can help to stimulate low-carbon investment across specific Sub-Saharan African (SSA) countries; the dynamic effects of fiscal shocks on low-carbon investment in Sub-Saharan African (SSA) countries and their interdependencies during the transition to low-carbon energy. To achieve these objectives, the study uses a Panel Vector Autoregression (PVAR) model, proposed by Holtz-Eakin et al. (1988). The findings show that low-carbon investment remains weak and is primarily driven by its own past values rather than fiscal support. Tax revenue exerts a negative long-run effect, while GDP per capita consistently promotes green investment. In conclusion, the fiscal systems of Sub-Saharan Africa (SSA) adjust slowly, and they lack the capacity to direct resources toward environmental priorities. This study recommends for stronger green fiscal frameworks, carbon pricing, targeted incentives, and enhanced climate finance in other to support sustainable low-carbon development in the region.

Keywords: Fiscal Policy, Low Carbon Investment, Sectoral Analysis.

JEL Classifications: B41, E62, Q50, H20

1. Introduction

Climate change is a worldwide phenomenon that is led by increasing human emissions of heat-trapping greenhouse gases. It is described as a statistical variation that persists for an extended period, typically for a decade or longer (Karatu, 2020). This has a widespread effect on the environment that results in glaciers and ice sheets shrinking, river and lake ice breaking up early, a shift to plant and animal geographical ranges, and plants blooming sooner than expected. Primarily, since the 1800s, human activities have been the major driver of climate change, as a result of burning fossil fuels like coal and gas (Cermak, 2024). In globally terms, Nigeria is among the top 10 when it comes to wealth of oil and gas resources, and the products gotten from this sector comprise around 90% of their exports (Karatu, 2020).

Greenhouse gas emissions are generated when fossil fuels are burnt, and this acts like a blanket that wraps around the Earth, trapping the sun's heat and raising temperatures. The main components of

these greenhouse gases include carbon dioxide (CO2) and methane (CH4). The oil and gas sector is a main source of greenhouse gas emission in Nigeria, that produces up to 90MtCO2 per annum according to Karatu (2020). These come from the use of petrol used for for driving cars or coal for used for cooking. In addition, clearing land and cutting down forests can also release carbon dioxide. This shows that agricultural, and oil and gas operations are major sources of methane emissions (Omodero & Alege, 2022). Energy, industry, transport, buildings, agriculture, and land use are also among the main sectors that cause greenhouse gases.

According to the World Meteorological Organization (2024), 2014 to 2024 was the warmest decade to be recorded, with a global mean temperature of 1.45 degrees Celsius above pre-industrial levels. Greenhouse gases will continue to contribute to global warming until the entire globe addresses the issue of carbon dioxide emissions in the atmosphere (Omodero & Alege, 2022). This sort of emission is possible to force out through the investment of green technology in developing economies such as Nigeria. The World Bank (2024) estimated that without increased mitigation, climate-related shocks could push more than 130 million people into poverty by 2030. This means that the economic implications of climate change further increase economic inequality and fiscal pressure, and reduces agricultural productivity, and increased fiscal pressures.

Consequently, Nigeria has intensified its commitments to decarbonization to lower emissions by 29% by 2030 and 32% by 2035 in its submission of the its third Nationally Determined Contribution (NDC 3.0) to the United Nations Framework Convention on Climate Change (UNFCCC) at the beginning of the fourth quarter of 2025 ahead of the 30th Conference of Parties (COP30). In its last pledge (NDC 2.0), submitted in 2021 ahead of COP26 in Glasgow, Scotland, Nigeria committed to an unconditional reduction of 20% and a conditional 47% reduction in emissions by 2030. The transition to a low-carbon economy therefore involves the reduction fossil fuels and coal energy use in order to transition seamlessly into a green economy.

A green economy is an economy that is low-carbon and natural resource efficient, and socially inclusive. In this economy growth in income and employment is as a result of public and private investments that aim to reduce carbon emissions, enhance energy, resource efficiency, and prevent loss of biodiversity and ecosystem service (Lee, et.al., 2024). Such investments are supported by targeted public expenditure, policy reforms and regulation changes. Environmental taxes and carbon pricing policies should also receive more attention, as these economic instruments are necessary to improve green investment and propel Nigeria towards achieving net zero by 2060, and at the same time reduce budget deficits (Osinusi, et.al., 2024).

The introduction of fiscal policy to improve green investment is the means through which the government manages and protects the environment just as they should in Section 20 of the Constitution of the Federal Republic of Nigeria 1999 (Karatu 2020). This constitution states that: the State shall protect and improve the environment and safeguard the water, air and land, forest and wildlife of Nigeria. The instruments that the government uses to achieve these objectives are budget, taxation, public expenditure, public works, public debt.

Initially, governments used basic rules and regulations (non-economic instruments) like bans to protect the environment, however, over time, they started to prefer economic or market-based methods such as taxes, subsidies or carbon trading because these methods were more effective (Sun & Feng, 2023). These market-based approaches are more profitable and stimulate the adoption of green technologies and investments in the field. One of the main economic methods used is pollution liability, and this includes a set of taxes that control the behaviour of producers and consumers (Feng & Ge, 2024). One of the basic policies is the fiscal policy through instruments such as environmental taxes, known as Pigouvian taxes (Manta et al., 2023).

Sub-Saharan African (SSA) countries, such as Nigeria, where the dependence on fossil fuel remains high, the use of environmental taxes gives room to incentives so as to control and conserve environmental effects into prices of products that have been produced with fossil fuels (Osinusi, et. al., 2024). These green taxes result in higher prices of fossil fuels, and this economically influences the decisions that people take while at the same time protecting the environment (Manta et. al., 2023). In addition, adding the cost of environmental damage to the prices of goods and services makes activities that bring about pollution more expensive, all the while creating a competitive advantage for clean and green alternatives. This method encourages firms and investors, both public and private, to shift their resources into low-carbon technologies and green infrastructure. When revenues that are gotten from these environmental taxes are channeled into renewable energy projects, the government builds the confidence and trust of firms and investors, both domestic and local, private and public. This is because investors are often attracted to economies that have clear and stable policies that support long-term sustainable goals (Yan et. al., 2023). This will further create a positive feedback loop between taxation, investment, and growth.

The implementation of these taxes also shows the government's commitment to climate action. According to the Federal Ministry of Finance (2025) the Federal Government unveiled the Nigerian Climate Investment Platform (NCIP), a country-led initiative designed to mobilize up to $500 million in climate finance for infrastructure, resilience, and adaptation projects. This strengthens the flow of green finance. Therefore, since climate change impacts macroeconomic outcomes, then fiscal policies that factor environmental and ecological issues should be designed and implemented. Therefore, this study examines the argument that green investment led by fiscal policy is important in the quest to decarbonize an economy such as Nigeria.

Building on this background, this study analyzes the nexus between fiscal policy and low-carbon investment in Sub-Saharan African (SSA) countries. The study aims to examine: (a) how fiscal policy instruments can help to stimulate low-carbon investment across specific Sub-Saharan African (SSA) countries (Angola, Congo, South Africa, Nigeria, Kenya, Tanzania, Senegal, Uganda, Ethiopia, Cote d'Ivoire, and Ghana); (b) the dynamic effects of fiscal shocks on low-carbon investment in Sub-Saharan African (SSA) countries and their interdependencies during the transition to low-carbon energy. The focus is on how fiscal policies affect green investment in Sub-Saharan African (SSA) countries, and this makes it a relevant contribution to knowledge in developing economies transitioning from fossil-fuels to green energy. By examining how fiscal policy instruments influence low-carbon investment in 11 specific Sub-Saharan African (SSA) countries, the study aims to improve the understanding of how the fiscal instruments constraints in these specific countries lead to their transition towards a sustainable future.

This study uses the panel vector autoregressive framework to address the issue of how energy shocks affect investment patterns in different sectors by utilizing a 7-year dataset and robust econometrics techniques. The remainder of this paper, following the introduction in Section one, the literature review and theoretical framework, is presented in Section two. Section three includes data and methodology. The analyzed results are presented in Section four, and policy implications and recommendations are discussed in Section five.

2. Literature review and Theoretical framework

This comprises a general review of the literature and the theoretical framework undertaken to situate the study and adequately highlight its relevance.

2.1 Theoretical review

The theoretical foundation of this study provides a better understanding of the nexus between fiscal instruments and low-carbon energy transition investments in various selected Sub-Saharan African (SSA) countries.

2.1.1 Keynesian Fiscal Theory

The Keynesian fiscal theory gives the foundational justification for government intervention in the economy through fiscal policy. According to John Maynard Keynes (1936), active fiscal policy is essential to stimulate aggregate demand, influence investment decisions, and promote macroeconomic stability. This theory explains the justification for state state-led investment and fiscal reorientation. Low-carbon projects usually face high cost, technological risk, and uncertain returns which discourages private investors, especially in developing economies with weak capital markets. The Keynesian theory supports the idea that fiscal policy (public spending, subsidies, and tax incentives) serves as a catalyst to stimulate the demand for green technologies and reduce investment risk. This type of investment increases productivity in Sub-Saharan African (SSA) countries, and it also reflects the multiplier and spillover effect that the Keynesian theory explains. This theory is relevant in the context of Sub-Saharan African (SSA) countries, since it is heavily dependent on public expenditure for growth and stability. This kind of reliance enables these economies to shift towards investing in green and sustainable development.

2.1.2 Pigouvian Tax Theory

In a Pigouvian world, the efficiency of government is the only conditioning factor for achieving a policy goal. Pigou (1920) developed the concept of externalities and explained that making the price of merchandise equal to the social marginal cost would lead to a more effective allocation of resources by the private sector. The Pigouvian tax is used to cover the negative externalities of the production process in the product's marginal cost. The Pigouvian tax is a system used to discourage negative externalities or activities that put a cost on the society (Kagan, 2025). According to Pigou (1920), when producers don't bear all the cost of production, negative externalities will prevent the market economy from reaching equilibrium. This, however, can be corrected by levying taxes that are equal to the externalized cost. An example of the Pigouvian tax is the tax on pollution from factories creating negative externalities manifesting through contaminated property, destroyed wetlands and streams, and affecting health.

Building on Pigou's idea that states that it is up to governments to use fiscal policy instruments to cover the negative externalities of the production process, environmental taxes have transformed into one of the most effective policy tools for reducing environmental degradation. The main aim of an environmental tax is not to provide income for governments but to organically deliver behavioral shifts amongst companies in order to use green technologies so that consumers use less polluting products and thus reduce pressure on the environment. These environmental taxes target multiple objectives, such as attaining a greener environment to supporting economic growth, and even reducing unemployment. Examples of the Pigovian tax include carbon taxes used to offset environmental pollution as a result of using petrol or gasoline, or tobacco taxes to address the strain on public healthcare systems caused by consuming tobacco products. Using these environmental taxes help to shift the burden of these externalities back to the producers and consumers who cause them and in addition, reduce greenhouse gas emissions and encourages the effective use of energy and green technologies in order to have a cleaner and healthier environment. This theory provides the framework used to understand the impact of fiscal policy instruments on the environment and productivity.

2.1.3 Green Growth Theory

This theory is a method that is used to balance long-term investment that is concerned with sustaining environmental wealth alongside with the need to reduce poverty. The Organization for Economic

Cooperation and Development (OECD 2011) stated that green growth is about fostering investment and economic growth at the same time, ensuring that natural assets continue to provide the resources and environmental services that will support people's well-being, growth, and give rise to new economic opportunities. The theory gives a clear understanding of how growth and the environment interact. The success of the green growth theory relies on addressing political obstacles and distributional concerns about the cost of change.

This theory provides the foundation for low-carbon investment as both a growth strategy and an environmental necessity. Hence, policies such as green subsidies, eco-tax reform, and public green investment improve environmental quality and stimulate production sectors. This study is primarily anchored on the green growth theory because it directly connects fiscal orientation, low-carbon innovation, and sustainable economic growth, and it also aligns with the objectives of the study. While the Keynesian theory acts as the foundation for fiscal stimulus, and the Pigouvian theory explains environmental correction, the green growth theory combines both, which is best suited for Sub-Saharan African (SSA) countries seeking to reduce emissions. This theory provides a clearer framework to understand the aim of sustaining growth while diversifying from fossil fuel dependency.

2.2 Empirical review

Previous studies have proved the establishment of the mentioned theories and the direct relationship between green fiscal policies, carbon emission reduction and corporate performance. The logic of this study is to check how fiscal policy instruments influence the rate of green investment and its effects on sectoral productivity. The works of Akamobi, et. al., (2025). analyzed the impact of green fiscal policies on energy use and environmental indicators in Nigeria, particularly looking at emissions and consumption from 1981 to 2023. Econometric methods that included the Ordinary Least Squares (OLS) regression, Autoregressive Distributed Lag (ADRL) models, Granger causality, and Augmented Dickey Fuller's (ADF) test were used. These methods were used regarding the relationship between fiscal policies (carbon taxation, subsidies for renewable energy, investments into clean energy technologies) and relevant environmental indicators. The results showed that there was a substantial negative relationship between carbon taxes and carbon emissions in the region. It was also established that the subsidization of renewable energy and investment into clean energy enhances the utilization of renewable resources. The Granger causality test showed that these policies improve fiscal energy consumption and environmental indicators.

Oye (2024) examined the macroeconomic and environmental effects of green fiscal and monetary instruments in Nigeria. This study used an environmental DSGE model, and it was calibrated and solved using the first-order Taylor approximation method. The first thing to be analyzed was the response of key macroeconomic aggregates to green relending rate and carbon tax shocks. Thereafter, the volatility effects of climate-augmented fiscal and monetary policy rules were compared to the standard rules. This resulted to two main features, firstly, the impulse responses revealed that carbon tax and lowered green relending rates reduced the pollution stock and carbon emission in the economy. However, both policy instruments primarily had contracting effects on the macroeconomy as output declined while inflation surged in response to shocks in carbon tax and green relending. This means that both green policy instruments can act as good climate mitigation policy but possess limited capacity for macroeconomic stabilization in Nigeria. Secondly, the business cycle effect of the climate-modified policy rules shows that augmented rules have better stabilizing properties than the standard rules. As a result, the central bank and fiscal authority can extend their mandates beyond price and output stabilization to include climate targets.

Mohamed, et.al., (2024) examined the implications of fiscal revenue on the African oil-dependent countries in the context of the low-carbon energy transition (LET). The study for the oil-dependent African oil countries (Algeria, Angola and Nigeria) between 1990 and 2020 used the newly developed fully modified OLS, dynamic OLS with canonical cointegrating regressions and other secondary data. The findings indicate that the LT policy does diminish oil and non-cost revenue for a number of specific countries within the panel, which suggests that the transition to low-carbon energy is reducing the fiscal revenue of oil-dependent African countries.

Ademola, et. al., (2024) applied the ARDL econometric approach on annual data extending from 1981 to 2022 to examine the effect of fiscal policy on the ecological footprint in Nigeria. The findings show that fiscal policy variables are both positively and negatively related to ecological footprints, and they are also statistically significant. Government tax revenue is found to reduce ecological footprints, while government expenditure escalates the environmental degradation in Nigeria during the period under review.

Emmanuel et. al., (2024) examined fiscal revenue implications for oil-dependent African countries in the face of low-carbon energy transition. The study combined the novel fully modified ordinary least squares, dynamic ordinary least squares, and canonical cointegrating regressions estimators to analyze data between 1990 and 2020 for three major oil-dependent African Countries (Algeria, Angola, and Nigeria). the findings showed that low-carbon energy transition reduces oil revenue and non-revenue for specific countries (Algeria, Angola, and Nigeria) and the panel. This means that low-carbon energy transition is lowering the fiscal revenue of oil-dependent African nations

Huang et. al., (2024) investigated the combined effect of agricultural contamination reduction and fiscal policy carbon reduction to support and promote green agriculture and low-carbon transformation. The study applied provincial panel data from 2007 to 2020 in China and used the spatial Dubin model to empirically examine the pollution reduction and carbon reduction effects of fiscal policies supporting agriculture, and calculated the synergistic effect of pollution reduction and carbon reduction. The findings revealed that non-point source agricultural pollution and agricultural carbon emissions have a tendency to grow and subsequently decrease, such as increasing from 2007 to 2015 and decreasing from 2016 to 2020. The results showed that agricultural carbon emissions and agricultural pollution have a positive geographical dependency in each province, and fiscal policies supporting agriculture have high-high and low-low spatial clustering features. Furthermore, fiscal policies that promote agriculture can lower local agricultural carbon emissions and pollution while also having a considerable beneficial spillover impact on neighboring provinces. According to the findings, the fiscal policy for supporting agriculture had a negative pollution reduction impact and a positive synergistic effect, which resulted in a synergistic effect of agricultural pollution reduction and carbon reduction.

Hu et.al., (2023) examined if carbon mitigation depends on the force of government or the autonomy of enterprises. The study differentiated between the roles of green fiscal policy and corporate green investment to check if they could guide enterprises on their own, in other to reduce carbon emissions. Theoretical and empirical methods were used to analyze green fiscal policies and corporate green investment mechanisms, which have nonlinear impacts on carbon mitigation in mathematical terms. The promotion of green fiscal policies on green investment was verified. The results showed that green fiscal policies are in support of enterprises that realize carbon mitigation by pressure. This stimulates green investment and achieves Innovation Compensation. In other words, carbon mitigation is triggered by green fiscal policies and this further drives green investment. This means that the green fiscal policy is an effective instrument for the government to stimulate green innovation since they are required to reduce carbon emissions.

Omodero and Alege (2022) investigated the influence of fiscal policy measures in reducing carbon

emissions in the ecosystem, using Nigeria as a case study. The analysis of the study spanned through the years 2000 to 2020 and made use of World Bank Development Indicators, the Federal Inland Revenue Service, and the Central Bank of Nigeria Statistical Bulletin as sources. The econometric tool of multiple regression was used to examine the effect of fiscal tools on climate change improvement, and it was shown that government funding had a negative intangible impact on climate change mitigation. In addition, tax income collection was positively irrelevant, and debt had a positive influence to reduce CO2 emissions.

3. Methodology and Empirical Analysis

This study applied a positivist research philosophy and a quantitative research technique, and an objectivist epistemology. This means that a meaningful reality exists and can be discovered. In other words, the research method applied in this study provides valid and dependable results

3.1 Data description and Apriori Expectation

This research paper used panel data from 2017 to 2024 obtained from the World Development Indicators (WDI) of the World Bank.

Table 1: Data description

Variable	Expected Sign	Units of Measure
Carbon intensity of GDP	Negative	kg CO2e per 2021 PPP $ of GDP
General government final consumption expenditure	Negative	% of GDP
Foreign direct investment, net inflows	Positive	% of GDP
Total debt service	Negative	% of GNI
GDP per capita	Positive	constant 2015 US$
Tax revenue	Negative	% of GDP

Source: Authors' compilation, 2025

Table 2: Names of Sub-Saharan African (SSA) Countries

S/N	Countries	S/N	Countries
01	Angola	**07**	Senegal
02	Congo	**08**	Uganda
03	South Africa	**09**	Ethiopia
04	Nigeria	**10**	Cote d'Ivoire
05	Kenya	**11**	Ghana
06	Tanzania		

Source: Authors' compilation, 2025

3.2 Estimation techniques

This paper is analyzed with the Panel Vector Autoregression (PVAR) model, proposed by Holtz-Eakin et al. (1988) as applied in the works of Yang et.al., (2023). In order to get an accurate result in estimating the relationship, the unit root and cointegration are determined because this helps the Panel Fully

Modified Least Squares (FMOLS) to be effective. The Impulse Response Functions (IRFs) and Forecast Error Variance Decomposition (FEVD) were employed to trace the dynamic responses of low-carbon investment to shocks in fiscal instruments.

The Impulse Response Functions (IRFs) show the direction and magnitude of the way the variable responds to a standard deviation shock. The Variance Decomposition quantifies the proportion of forecast error variance explained by each shock over time. The Cholesky Decomposition technique was utilized to separate the effects of shocks so that they do not overlap, making the impulse response results much easier and clearer to interpret (Gershon et. al., 2019). This method allows the short-run shocks in the fiscal instruments to be differentiated from the long-run structural trends in low-carbon investments. The statistical software Eviews was employed in analyzing the data.

3.3 Model specification

The empirical model follows the works of Yang et.al., (2023), and Gershon et.al., (2019). The model follows the standard Panel Vector Autoregression (PVAR) model, proposed by Holtz-Eakin et al. (1988), has the following vectoral form of the endogenous variables:

Where each variable is:

TRV: Tax revenue (% of GDP)

LCIN: Log of Carbon intensity of GDP (kg CO2e per 2021 PPP $ of GDP)

GCE: General government final consumption expenditure (% of GDP)

FDI: Foreign direct investment, net inflows (% of GDP)

TDS: Total debt service (% of GNI)

LGDP: Log of GDP per capita (constant 2015 US$)

The PVAR model with country fixed effects is:

Where:

The PVAR(1) system (country fixed effects included) is:

Equation-by-equation (each):

FMOLS estimates the long-run relationship between low-carbon investments and fiscal instruments. The cointegrating equation can be written as:

4. Results and Discussion

Table 3 shows that on an average, Tax Revenue (TRV) is 13.26%, while Government Consumption Expenditure (GCE) and Total Debt Service (TDS) have mean values of 10.42% and 4.66% respectively. This means that government spending and debt servicing remain higher than the overall tax revenue performance across the countries considered. Foreign Direct Investment (FDI) also has a mean value of 2.11% and this means there are moderate inflows. The average value of Low-carbon Investment (LCIN) is negative (-1.45). This means that investments in green or low-carbon projects remain low among the specific Sub-Saharan African (SSA) countries. GDP per capita (LGDP) has the highest mean value of 740.13, which shows large differences in economic size across the SSA countries.

With the standard deviation, there is moderate variability across the variables, where LGDP has the highest volatility, and this explains that economic size fluctuates greatly across countries and over time.

TDS and TRV also show noticeable variation, while LCIN shows relatively lower variability compared to other macroeconomic indicators. FDI shows moderate volatility, consistent with the nature of capital flows in developing economies.

The skewness values show that TRV, GCE, TDS, and LGDP are positively skewed, and this means that their distributions are tilted to the right. They have high extreme values that pull the distribution. FDI is slightly skewed to the left, and LCIN is almost symmetric with a skewness close to zero. The Jarque-Bera statistics show that TRV has a probability slightly above the 0.05 threshold, which means it is approximately normally distributed. However, the probabilities for LCIN, GCE, TDS, FDI, and LGDP are all below 0.05, and this indicates that these variables deviate from normality.

Table 3: Descriptive Statistics

	TRV	LCIN	GCE	TDS	FDI	LGDP
Mean	13.26422	-1.453128	10.42343	4.662766	2.111565	740.1331
Median	12.24424	-2.146741	9.204414	2.961106	1.994594	7.775705
Maximum	26.00546	0.558908	20.62034	17.69492	15.60446	6125.692
Minimum	3.407568	-3.718219	4.400000	-3.057266	-10.03838	6.155928
Std. Dev.	5.669363	1.367754	3.948770	4.498729	3.614115	1316.743
Skewness	0.619626	0.095659	0.956612	1.514329	-0.133167	2.525867
Kurtosis	2.765764	1.396851	3.224618	4.588405	6.630179	10.06309
Jarque-Bera	5.765976	9.449255	13.45194	42.39729	48.02810	273.3513
Probability	0.055967	0.008874	0.001199	0.000000	0.000000	0.000000
Sum	1153.987	-126.4221	906.8381	405.6606	183.7061	64391.58
Sum Sq. Dev.	2764.185	160.8847	1340.980	1740.516	1123.317	1.49E+08
Observations	87	87	87	87	87	87

Source: Eviews' computation, 2025 based on WDI data

Table 4 shows that the variables follow similar trends, although FDI is stationary at levels, while the others are stationary at the first differencing. This means that most of the variables are integrated at the order one, I(1), while FDI is integrated at order zero, I(0). At levels, the p-values of TRV, LCIN, GCE, TDS and LGDP are greater than 0.05, which means that the null hypothesis of the unit root can't be rejected for these variables. This result still gives leverage to running a cointegration analysis to avoid a spurious regression since the majority of the variables are I(1).

Table 4: Unit Root

Variables	**At Levels**		**1st Difference**		**Decision**
	p-value	t-stat	p-value	t-stat	
TRV	0.9984	7.43572	0.5093	20.0604	I(1)
LCIN	0.9479	12.4265	0.5158	18.5420	I(1)
GCE	0.9879	9.81302	0.0080	41.0856	I(1)
FDI	0.4806	21.6549	0.0670	32.6492	I(0)
TDS	0.9552	12.1026	0.0001	54.3221	I(1)
LGDP	0.9230	13.3472	0.5078	20.1964	I(1)

Source: Eviews' computation, 2025 based on WDI data

To examine if a long-run equilibrium relationship exists among the fiscal policy variables and low-carbon investment in Sub-Saharan African (SSA) countries, the Pedroni (1999) residual-based panel cointegration test was applied. This is a suitable method for heterogeneous panel data, and it allows intercepts and slope coefficients to vary across cross-sections, which is important for this multi-country SSA dataset. Table 5a shows that most of the statistics, which are Panel v, Panel rho, and Group rho, fail to reject the null hypothesis. This means that they do not show evidence of a long-run relationship. However, the PP-based tests (Panel PP and Group PP) strongly reject the null hypothesis with p-values of 0.0000. The PP tests are better at detecting cointegration, and their significance shows that a long-run relationship exists among the variables, regardless the other statistics are not significant.

Table 5a: Cointegration test

Statistic	Value	p-value	Decision
Panel v-Statistic	-2.3365	0.9903	Fail to reject H0
Panel rho-Statistic	3.0336	0.9988	Fail to reject H0
Panel PP-Statistic (weighted)	-11.7227	0.0000	Reject H0
Group rho-Statistic	3.8589	0.9999	Fail to reject H0
Group PP-Statistic	-7.7634	0.0000	Reject H0

Source: Eviews' computation, 2025 based on WDI data

Table 5b summarizes the findings in Table 4a, and it explains that both the within-dimension and between-dimension tests have mixed results because only the PP statistics are significant. Despite this, the overall conclusion is that cointegration exists. This is because the PP tests provide consistent evidence of a long-run relationship, which supports the presence of equilibrium among the variables over time.

Table 5b: Cointegration test

Test Group	Result	Interpretation
Within-dimension	Mixed	Only PP significant
Between-dimension	Mixed	Only PP significant
Overall	Cointegration exists	Long-run relationship supported by PP statistics

Source: Eviews' computation, 2025 based on WDI data

4.1 Empirical Estimation

Table 6 shows the results of the Panel Fully Modified Least Squares (FMOLS) estimation with Low-carbon Investment (LCIN) as the dependent variable. In the result, Tax Revenue (TRV) has a negative and significant effect on Low-carbon Investment (LCIN), with a coefficient of –0.140 and a p-value of 0.0348. This means that higher tax revenue is associated with slightly lower investment in low-carbon projects. Government Consumption Expenditure (GCE), Total Debt Service (TDS), and Foreign Direct Investment (FDI) have coefficients that are not statistically significant. They do not show a clear long-run effect on low-carbon investment in this sample. The GDP per Capita (LGDP), on the other hand, has a positive and highly significant effect (coefficient 0.000633, p-value 0.0000), showing that larger economies tend to have higher levels of low-carbon investment.

The R-squared value of 0.537 indicates that the model explains about 54% of the variation in low-carbon investment, while the adjusted R-squared of 0.421 accounts for the number of variables in the model. In conclusion, the results explain that economic size and tax revenue play notable roles in influencing long-run low-carbon investment, while government spending, debt service, and FDI do not have a significant effect.

Table 6: Panel Fully Modified Least Squares (FMOLS)

Dependent Variable: LCIN Sample (adjusted): 2018 2024 Periods included: 7 Cross-sections included: 11 Total panel (unbalanced) observations: 76 Panel method: Pooled estimation Cointegrating equation deterministics: C Coefficient covariance computed using default method Long-run covariance estimates (Bartlett kernel, User bandwidth = 6.0000)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
TRV	-0.140047	0.064845	-2.159704	0.0348
GCE	0.042684	0.106308	0.401514	0.6895
TDS	-0.006248	0.081570	-0.076594	0.9392
FDI	0.018995	0.082748	0.229551	0.8192
LGDP	0.000633	0.000127	4.987805	0.0000
R-squared	0.537095	Mean dependent var		-.682251
Adjusted R-squared	0.421369	S.D. dependent var		1.312069
S.E. of regression	0.998062	Sum squared resid		59.76769
Long-run variance	0.993269			

Source: Eviews' computation, 2025 based on WDI data

Figure 1 shows how Low-carbon Investment (LCIN) reacts to a shock in Tax Revenue (TRV), Government Consumption Expenditure (GCE), Total Debt Service (TDS), Foreign Direct Investment (FDI), and GDP per Capita (LGDP). TRV shows that LCIN initially responds negatively to a shock in tax revenue, but after a few periods, the response becomes positive and stabilizes, indicating that over time, higher tax revenue may encourage low-carbon investment. GCE shows a mostly positive response, suggesting that increases in government spending stimulate low-carbon investment. TDS shows an initial negative reaction, followed by a gradual rise towards zero, and this means that higher debt service initially weakens investment, but its effect reduces over time. FDI shows a small negative effect initially, turning slightly positive in later periods, indicating that foreign investment has a modest delayed impact on low-carbon investment. Finally, LGDP shows a positive response throughout the periods. This means that larger economic size consistently promotes low-carbon investment.

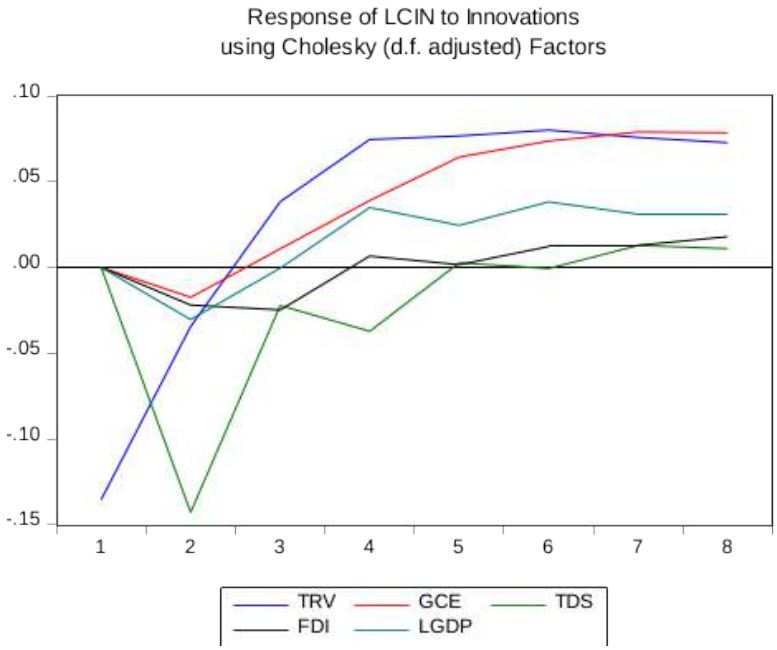


Figure1: PVAR and Impulse Response Function (IRF)

Source: Eviews' computation, 2025 based on WDI data

Table 7 shows the variance decomposition results of how the influence of each variable evolves. For TRV, the short run is 100% dominated by its own shocks, but this influence reduces to about 65.7% by period 10. Over time, GCE (15.2%) and LCIN (14.4%) become the major external contributors, meaning that government consumption and low-carbon investment increasingly shape TRV's fluctuations. LCIN is initially driven almost entirely by its own past values (97.5%), but its self-influence also drops to 88.6% as TRV (5.3%) and GCE (3.2%) begin to play more meaningful roles, showing that these factors gradually affect investment decisions. For GCE, its self-dependence decreases sharply from 92% to 64.4% by period 10, while TRV (16.8%) and FDI (12.9%) show up as the strongest external drivers, indicating that both trade-related variables and foreign investments become important in explaining government consumption patterns. TDS also shows a reducing self-influence, from 91.8% to 69.4%, with GCE (16.8%) and LCIN (11.9%) increasingly explaining variations in debt servicing, meaning that fiscal spending and investment behaviour contribute to long-run debt pressures. FDI begins strongly self-driven (85%), but it reduces to 74.5% by the tenth period, with GCE (11%) and TDS (6%) becoming more influential, showing that government expenditure and debt conditions shape foreign investment flows over time. Lastly, LGDP stands out as the most stable variable, with its own past values (51.6%) and LCIN (42.9%) consistently explaining almost all its fluctuations even in the long run. This means that GDP dynamics are largely influenced by internal economic momentum and sustained low-carbon investment rather than short-term shocks from other variables.

Table 7: Variance Decomposition

Variance Decomposition of TRV: Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP
1	1.692898	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	2.402125	97.21654	0.086602	0.210135	0.685938	1.361997	0.438785
3	2.788696	94.52784	0.380055	1.209158	2.245728	1.283202	0.354019

4	3.088379	90.68178	0.391535	2.528250	4.388906	1.168794	0.840739
5	3.337766	86.02591	0.338979	4.216897	6.869536	1.058274	1.490401
6	3.545685	81.41534	0.318043	6.187765	9.101785	0.963571	2.013501
7	3.726766	76.96742	0.376108	8.295409	11.10490	0.882772	2.373390
8	3.888768	72.83448	0.537288	10.41635	12.77836	0.818161	2.615370
9	4.036759	69.05369	0.790584	12.47303	14.15427	0.766884	2.761541
10	4.173339	65.65538	1.114930	14.41045	15.24142	0.728708	2.849117

Variance Decomposition of LCIN:

Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP
1	0.849326	2.537423	97.46258	0.000000	0.000000	0.000000	0.000000
2	0.963664	2.098369	95.52480	0.032756	2.192915	0.051844	0.099312
3	0.996841	2.109112	95.54674	0.042376	2.098748	0.110203	0.092821
4	1.012813	2.584590	94.73868	0.188895	2.168199	0.111075	0.208564
5	1.020897	3.108127	93.80239	0.582077	2.134689	0.109575	0.263137
6	1.028650	3.667278	92.62385	1.087372	2.102659	0.121990	0.396850
7	1.035551	4.153989	91.48447	1.654458	2.089923	0.135912	0.481243
8	1.042057	4.589123	90.40704	2.201049	2.074920	0.163857	0.564005
9	1.047942	4.964553	89.43742	2.708569	2.071863	0.196519	0.621074
10	1.053341	5.300325	88.56155	3.158274	2.068636	0.239276	0.671937

Variance Decomposition of GCE:

Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP
1	0.945982	5.934370	2.111792	91.95384	0.000000	0.000000	0.000000
2	1.405991	5.389234	1.451008	90.44251	0.013099	1.344876	1.359277
3	1.703771	5.188466	1.060145	89.48250	0.008953	2.578415	1.681517
4	1.914566	5.755454	1.395435	86.71415	0.146310	4.142823	1.845824
5	2.074299	6.903300	1.877573	83.20667	0.361383	5.795397	1.855680
6	2.206043	8.534267	2.229833	79.17842	0.667976	7.509582	1.879927
7	2.318707	10.48828	2.366390	75.14639	0.949791	9.125285	1.923866
8	2.418838	12.61079	2.349998	71.24357	1.199649	10.59049	2.005496
9	2.508447	14.75071	2.251544	67.65136	1.390028	11.84923	2.107130
10	2.589002	16.79947	2.129400	64.42248	1.530007	12.89651	2.222132

Variance Decomposition of TDS:

Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP
1	1.987264	0.426132	7.329997	0.475071	91.76880	0.000000	0.000000
2	2.282259	0.562830	11.52746	1.695659	84.14251	1.149063	0.922475
3	2.695269	0.412246	9.797567	3.787122	84.48332	0.854937	0.664807
4	2.953199	0.353086	10.47259	5.723657	81.47632	0.757779	1.216572
5	3.219208	0.300276	10.30854	7.816113	79.79764	0.640905	1.136528
6	3.428690	0.265043	10.69919	9.854935	77.37839	0.567753	1.234690
7	3.624581	0.238356	10.93126	11.79659	75.31230	0.508044	1.213444
8	3.792491	0.217938	11.30454	13.61020	73.16284	0.468569	1.235911
9	3.944208	0.204093	11.61703	15.28437	71.22122	0.440475	1.232809
10	4.077814	0.202802	11.93576	16.81531	69.36938	0.431130	1.245615

Variance Decomposition of FDI:

Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP

1	1.968583	2.086530	0.060282	2.694114	10.11455	85.04453	0.000000
2	2.429162	3.244699	1.036614	1.867338	9.243285	78.31171	6.296353
3	2.665532	2.893404	1.001427	2.475325	8.384297	79.98445	5.261102
4	2.854261	2.527933	0.947086	3.578565	8.023995	80.26005	4.662367
5	2.999488	2.368019	0.971499	4.882443	7.410335	80.08789	4.279820
6	3.110694	2.352298	1.122277	6.247400	6.971727	79.28936	4.016937
7	3.201033	2.435432	1.331586	7.603897	6.601700	78.17962	3.847768
8	3.272739	2.544327	1.611143	8.866442	6.324340	76.93495	3.718793
9	3.330039	2.644364	1.915263	10.01397	6.110142	75.69227	3.623988
10	3.375109	2.712976	2.226943	11.03222	5.948804	74.53041	3.548646

Variance Decomposition of LGDP:

Period	S.E.	TRV	LCIN	GCE	TDS	FDI	LGDP
1	783.5741	0.620294	44.33272	2.173385	0.019466	0.083617	52.77052
2	873.6285	0.502953	44.02656	2.669822	0.054431	0.104553	52.64168
3	894.9191	0.494608	43.82533	2.778651	0.315690	0.179757	52.40597
4	900.2556	0.505086	43.58711	2.778399	0.559963	0.316438	52.25301
5	902.7628	0.518056	43.37673	2.764171	0.807702	0.434124	52.09922
6	904.2827	0.525625	43.23123	2.756214	1.002775	0.531442	51.95272
7	905.4695	0.529353	43.11983	2.752243	1.176173	0.600638	51.82177
8	906.3927	0.530799	43.03603	2.749629	1.317488	0.649660	51.71639
9	907.1330	0.531371	42.96996	2.746751	1.438087	0.681615	51.63222
10	907.7188	0.531576	42.91850	2.743707	1.537573	0.702211	51.56643

Cholesky Ordering: TRV LCIN GCE TDS FDI LGDP

Source: Eviews' computation, 2025 based on WDI data

4.2 Discussion of the Results

The FMOLS estimates show that tax revenue has a statistically significant negative effect on low-carbon investment, meaning that increases in tax mobilization may come with fiscal trade-offs that reduce the fiscal capacity for green projects. Conversely, GDP per capita has a strong positive effect, indicating that economically advanced countries invest more in low-carbon activities in SSA countries. Government consumption, debt service, and FDI have no significant long-run impact. The dynamic analysis through impulse responses further highlights that shocks to tax revenue initially reduce low-carbon investment before turning positive, while GDP per capita shocks consistently promote it. The variance decomposition results show that over time, low-carbon investment becomes increasingly influenced by tax revenue and government spending, while GDP per capita remains largely driven by its own momentum and by sustained investment in low-carbon sectors.

The results align with the findings of Omodero & Alege (2022), their study found that government spending has a negligible negative impact on environmental degradation, meaning that even when the government spends, it is not directed toward pollution management or green priorities. This is in line with the FMOLS results, where government consumption expenditure has no significant long-run effect on low-carbon investment, meaning increases in government spending are not targeted toward green sectors. In contrast, Omodero & Alege (2022), argues that tax revenue has a positive but insufficient effect on reducing CO_2 emissions. This means that although tax collection helps environmental improvement to some extent, it does not reduce emissions enough to be effective. Whereas, in this study, tax revenue has a negative and significant effect on low-carbon investment, meaning that higher tax revenue is associated with less investment in green projects.

5. Conclusion and Recommendations

The empirical results of this study show the interaction between fiscal variables and low-carbon investment across Sub-Saharan African (SSA) countries. The results show that low-carbon investment remains weak on average, and its behaviour is largely driven by its own past values rather than strong fiscal support. Tax revenue was found to have a negative and significant long-run effect on low-carbon investment, suggesting that fiscal pressure or competing budgetary priorities may crowd out green projects. By contrast, GDP per capita consistently promotes low-carbon investment, both in the long-run estimation and in the dynamic responses, highlighting that stronger and more diversified economies are better positioned to fund environmental initiatives. Government spending, debt service, and foreign direct investment do not show significant long-run effects on low-carbon investment, indicating that current fiscal structures are not optimized for environmental goals.

Generally, this study shows that while SSA countries have established fiscal frameworks, these frameworks are not yet aligned with the needs of a low-carbon development pathway. Fiscal institutions show slow adjustment patterns, with high persistence in key macroeconomic variables and a limited capacity to redirect fiscal resources toward green priorities. This highlights the need for a more intentional and strategically designed fiscal architecture that supports low-carbon investment, reduces structural constraints, and promotes environmental resilience across the region.

SSA countries should adopt a forward-looking green fiscal framework that adds climate considerations into mainstream fiscal planning. Governments should restructure their tax systems to incorporate environmental tax instruments, particularly carbon pricing, while avoiding excessive tax burdens that may discourage private green investment. Introducing green tax incentives, such as tax credits and rebates for renewable energy adoption, can attract private sector participation. Public expenditure should strategically shift toward low-carbon infrastructure, clean energy systems, and climate-smart technologies, especially in countries with large fiscal gaps. Strengthening green borrowing instruments such as green bonds, concessional loans, and climate finance facilities will reduce reliance on traditional debt servicing and enhance long-term environmental investment. In addition, regional cooperation across SSA can foster shared financing mechanisms, knowledge exchange, and coordinated environmental standards. While this study has achieved its objectives, its findings are limited by the availability of recent and comprehensive data on low-carbon investment indicators. Future research could explore nonlinear fiscal-environment relationships and apply more advanced dynamic modelling techniques to better capture long-term adjustment patterns in low-carbon investment behaviour.

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Impact of Digital Infrastructure on Nigerian Economic Growth

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ABSTRACT

This research examines the impact of digital infrastructure on Nigerian economic growth, drawing on theories of digital infrastructure, digital public infrastructure, and neo-classical economic growth. This topic is chosen for research because there's a significant effect of more positive than negative impacts on Nigeria's economy through close-knit upgrades of software engineering, coding classes, and investments in direct or third-party forms by software and hardware companies. The independent variables namely; internet setup in rural and urban areas had to be measured by digital infrastructure index(DII); broadband penetration rate (BPR) as regard the communication companies while choosing between Airtel, MTN, GLO or 9JA mobile; training of policy makers and economic analysts with their understanding careened by Key Performance Indicators (KPIs) and; a retained GDP's response to internal and external influence. There's a research gap in focusing on the setup of digital infrastructure without considering the inclusivity of different segments of Nigerians and the extent to which these citizens are trained on digital updates on a continuous basis. The VEC Model also enabled the analysis of the Granger causality test, which examines the short-term and long-term relationships between variables. The data collection mode included in my study was secondary data. Additionally, cointegration is an assumption of the chosen model, which was deemed acceptable for the research. The findings indicate that broadband development and training are key long-term drivers of digital infrastructure in Nigeria. In conclusion, the results suggest a stable short-term adjustment process, where internet usage, broadband expansion, and training efforts collectively drive long-term digital infrastructure growth. On a final note, the results also imply short-term stability and a tendency for growth rates to adjust over time.

Keywords: Digital infrastructure, VEC model, Economic growth **JEL Classifications: L86, H54**

1. INTRODUCTION

Digital presence in the economy has been and continues to be a significant asset in extending economic strategies compared to previous phases in Nigeria's gross domestic product (GDP) and other key metrics, as well as macroeconomic variables. Digital infrastructure cuts across every sector in the economy, as it is the whole assuring guarantee to create awareness of businesses, according to the market niche per product or total business. In Nigeria, data farms are being rented or outsourced, in addition to the actual physical address of the companies, and, more importantly, firewalls are required to prevent information leaks. Iwedi (2024) conducted research that brought to light the fact of an exponential rise in digital infrastructure, exemplified by the proliferation of Automated Teller Machines (ATMs), Point of Sale (POS) machines, and web banking accounts. According to Guanah and Bebenimibo(2025), digital technology has emerged as a powerful driver of economic transformation globally.

Nigeria, one of Africa's largest economies, is seeking to leverage this technology to drive its economic growth. TechCabal (2022) reports that the ICT sector contributed more to Nigeria's GDP than the oil sector in the second quarter of 2022. It is the first time the ICT sector has surpassed the oil sector in

contribution to Nigeria's GDP. According to the Nigeria Digital Economy Diagnostic report by the World Bank, Nigeria can fully unleash new economic opportunities, create jobs, and transform people's lives with improvements in digital connectivity, skills, financial services, and other core areas of digital development (World Bank, 2019). Guobadia (2023) argues that the government needs to do more to promote the growth of the digital economy, including investing in infrastructure, providing digital skills training, and creating a more supportive regulatory environment.

In Nigeria, the wisdom gained from those with technological knowledge might be non-restricted to the country due to low remuneration; hence, they tend to freelance or travel outside the country. Digital finance infrastructure is the integrated network of technological and organizational elements that digitally facilitates the delivery and operation of financial services. It encompasses the hardware, software, networks, protocols, and regulatory frameworks that enable the seamless execution of various financial transactions, including payments, transfers, investments, and other economic activities, using digital channels such as mobile devices, computers, and the internet (Iwedi, 2022). It is based on the fact or assumption that Nigeria and other African countries benefit from the presence of a vast number of young people as part of their population.

Instead of traditional tertiary education, they attend tech centers to gain training in various aspects, such as Virtual Assistance, AI Career Essentials, content creation, graphic design, data science, analysis, and engineering, as well as other upcoming courses. While working, before the researcher's admission to Covenant University (CU), one of her past employers primarily dealt with building and managing data centers. Digital infrastructure becomes very important if the soft aspect is kept very secure. Ramayanti, Rachmawati, Azhar, and Nik Azman (2024) state that, especially in the rural areas, the National Policy on Information and Communication Technology has been crucial in restoring the health of technological platforms like power and broadband networks. The policy places significant emphasis on entrepreneurship and the digital economy, making efforts to stimulate startup creation, attract investment, and establish more favourable legislation.

The creation of technology incubation centers and innovation villages has helped create conducive environments for startups, promoting interconnectivity and growth within the technology industry. This study examines the ceteris paribus effect between the independent variable of digital infrastructure and the dependent variable of Nigeria's economic growth. There is a use of time series for thirty (30) years' worth of data to create the time series econometrics with the EViews application. There are four (4) sections after the introduction, including the literature review, methodology, discussion of findings, and the conclusion and expected policy implications. This paper aims to assess the impact of digital infrastructure on Nigeria's economic growth.

2. LITERATURE REVIEW

The preamble for this aspect is that digital infrastructure and economic growth would be theoretically, empirically, and conceptually reviewed.

2.1 Theoretical Review

The decision is made to examine theories related to both variables of this study and is presented in this section.

2.1.1 Socio-technical Systems Theory

Socio-Technical Systems Theory (STS) provides a valuable conceptual framework for understanding organizational resistance. Originating from (Trist & Emery, 1973) at the Tavistock Institute, STS theory posits that organizational performance depends on the joint optimization of social and technical subsystems. This view aligns with (Bostrom & Heinen, 1977), who emphasized the need to consider employee attitudes, work practices, and institutional norms in conjunction with technical design. Mumford (2000) also championed participatory system design, arguing that systems developed without employee input are more likely to provoke resistance and fail to achieve intended outcomes. It posits that technological systems must align with social, organizational, and infrastructural conditions to achieve optimal functionality (Gavi, 2025).

2.1.2 Innovation Diffusion Theory

It explains how technological innovations spread through a population over time. It categorizes adopters as innovators, early adopters, early majority, late majority, and laggards, depending on factors such as awareness, perceived benefits, and resource availability (Gavi 2025). Rogers' theory of innovation suggests that innovation diffusion consists of five stages: cognition, persuasion, decision-making, implementation, and confirmation. Individuals progress from becoming aware of the innovation, forming attitudes, making choices, putting them into practice, to ultimately confirming or adjusting their decisions, thereby completing the entire diffusion process (Jin, 2025).

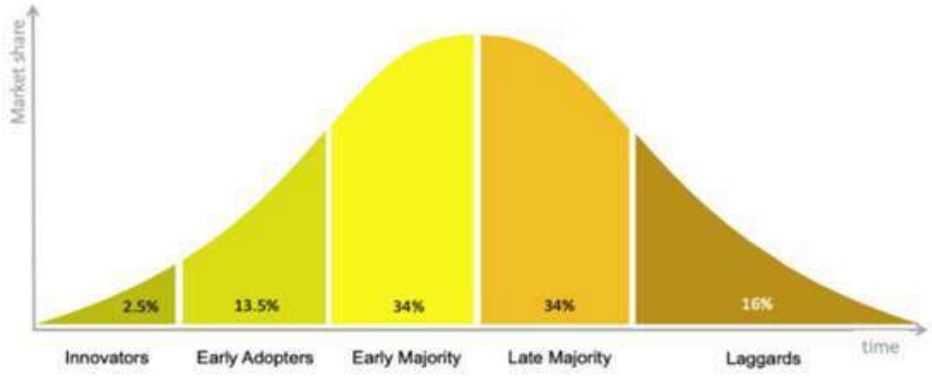


Fig 2.1: Roger's Adoption Curve

2.1.3 Neo-Classical Growth Theory

Robert Solow and Trevo brought this theory into action, leading to consequential Solow-Swan educational stances. The ultimate objective of research on economic growth is to determine whether there are possibilities for raising overall growth or living standards in developing countries closer to those of the world leaders. The Solow-Swan model is crucial for understanding theories of economic development. The principal conclusion of the Solow model is that the accumulation of physical capital cannot account for the vast growth in output per person over time or the enormous geographic differences in output per person. The Solow model is also known as the Solow-Swan model. The Solow model focuses on four variables: output (Y), capital (K), labor (L), and "knowledge" or the "effectiveness of labor" (A). At any time, the economy has some labor and knowledge, which combine to produce output. The production function takes the form $Y(t) = F(K(t), A(t), L(t))$, (1.1) where t denotes time.

Specifically, the central conclusion of the Solow model is that if the returns that capital commands in

the market are a rough guide to its contributions to output, then variations in the accumulation of physical capital do not account for a significant part of either worldwide economic growth or cross-country income differences (Romer, 2012). In a nutshell, digital infrastructure would serve as a form of capital accumulation, and this would have an observable effect on Nigeria's economic growth, according to Robert's and Trevor's theory and the adjudicated model.

2.2 Empirical Review

Other theories may also be related to research, with the digital divide theory and the technical acceptance model being more frequently cited. Bridging the digital divide is essential for promoting equity, economic development, and social inclusion in the digital age. Governments, organizations, and communities must collaborate to ensure everyone has access to the necessary digital tools and skills to participate in the digital economy and society. Addressing the digital divide requires a comprehensive approach that addresses the underlying causes of inequality. Addressing the divide includes investing in digital infrastructure, providing digital skills training, and implementing policies that promote digital inclusion (Norris, 2020). Jacks et al. (2024) recommended investigating the potential for new and emerging technologies to address specific telecommunication challenges faced by different regions.

This potential includes exploring satellite technology, low-cost broadband solutions, and mobile development applications. Finally, comparative studies on policy and regulatory frameworks that have successfully facilitated telecommunication development will be conducted, focusing on lessons learned and best practices that can be adapted and applied across different regions. Asalu (2025) in a techeconomy newsletter stated that, by doubling down on strategic infrastructure investments, fostering seamless policy cooperation, and leveraging the combined power of government and industry, we can lay a resilient foundation for an inclusive, globally competitive digital economy.

An Owerri-based research by Nigerians had these recommendations; Owners and managers of international businesses in the South-East can be technologically driven by investing more in digital infrastructures such as IT infrastructure for a more reliable internet connectivity to enhance business digital connectedness; Corporations and their suppliers should use digital tools such as cloud computing and data security not only to detect and resolve problems that may affect the business interconnectedness but also to improve communication and collaboration; International businesses should adopt stronger digital networks of all sizes for easy use of technologies such as Internet backbone and broadband to enhance their operations and drive innovation, and; Businesses should adopt mobile telecommunication networks to exchange messages between the nodes and provide cell service and related services to mobile phones users (Donatus et. al 2024).

The findings revealed that the effect of ICT on economic diversification is sensitive to the measure of ICT employed. At the same time, some evidence has to be found by the researcher in light of these activities regarding ICT adversely affecting economic diversification in SSA, which is efficiently explained as the results from challenges associated with poor ICT connectivity arising from poor ICT infrastructure provision as well as poor access to enabling infrastructure as electricity in the countries(Owolabi, Adedeji, Aderounmu, Oku, & Ogunbiyi, 2023).

2.3 Conceptual Review

2.3.1 Concept of Digital Infrastructure

Ensuring affordable data and devices is equally crucial. Despite almost 29% of Nigerians regularly using the internet, high data costs and expensive smartphones continue to exclude a significant portion of our

population. The absence of a local smartphone assembly plant keeps entry-level prices stubbornly high. To truly democratize digital access, we must explore lowering import duties, actively encouraging local manufacturing, and implementing targeted subsidies for broadband services. Furthermore, digital infrastructure cannot thrive without a stable electricity supply because unreliable power leads to inconsistent uptime and unreliable service delivery, particularly in rural communities. We must fully embrace micro-grid solar solutions and renewable backup systems (Oluwole Asalu, 2025).

2.3.2 Concept of Gross Domestic Product (GDP)

It was developed in 1934 by a Russian-American economist named Simon Kuznets. The GDP composition of GDP includes consumption, investment, government spending, and net exports. In one of the recent lecture materials, the previous statement can be explained as follows: goods and services purchased by consumers are also known as total demand; fixed investment includes that of residents and non-residents; government spending excludes government transfers; foreigners buying Nigerian goods and services; and; imports would be foreign goods and services to domestic consumers, domestic firms and the domestic governments.

3.0 METHODOLOGY

More of time series econometrics is a great estimation technique as data is sourced in regard to likely independent variables, namely, internet setup in rural and urban areas, which is a measure of digital infrastructure index(DII) through population of internet users, overall broadband penetration, and fixed broadband; broadband penetration rate (BPR) as regard of the communication companies being used between Airtel, MTN, GLO or 9JA mobile; training of policy makers and economic analysts which can be evaluated by Key Performance Indicators(KPIs) and; these would retain GDP's response to internal and external influence.

This research utilizes annual data from 1994 to 2024 to examine how the government transitioned from analog to digital infrastructure and the subsequent improvements that resulted. The economic paradigm applied herein is the Vector Error Correction (VEC) Model, which is typically used when assessing the influence on economic growth. In the VEC Model, the cointegration rank shows the number of cointegrating vectors. For instance, a rank of two indicates that two linearly independent combinations of the non-stationary variables will be stationary. A negative and significant coefficient of the ECM suggests that any short-term fluctuations between the independent and dependent variables will give rise to a stable long-run relationship between the variables (Ojoko et al, 2022). The VEC Model also enables the analysis of the Granger causality test, which examines the short-term and long-term relationships between variables. Additionally, cointegration is an assumption of the chosen model, which is acceptable for the research.

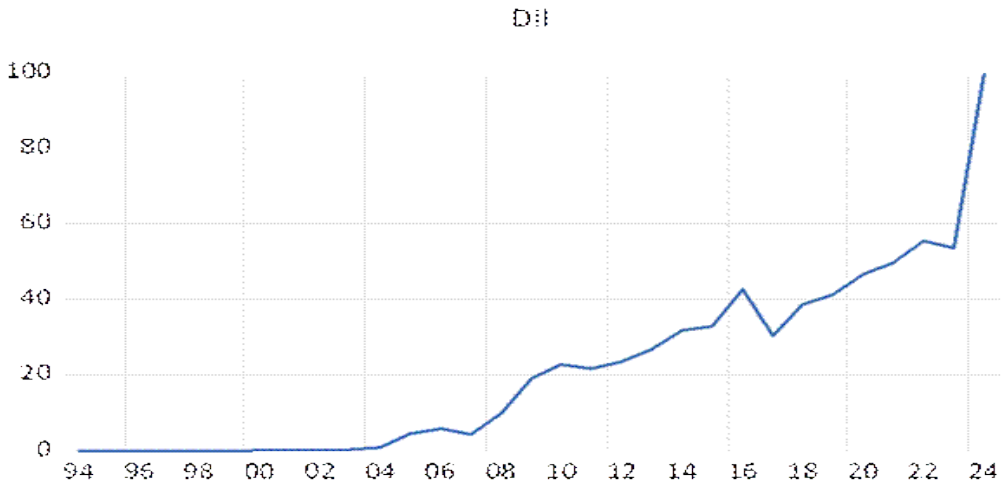


Fig 3.1: Nigeria's DII Trend *Source: EViews*

The graph illustrates a sharp upward trend in Nigeria's Digital Infrastructure Index (DII) from 1994 to 2024. The index remained nearly flat through the late 1990s, indicating minimal digital development, but began to rise steadily in the early 2000s as internet and broadband penetration expanded. Moderate fluctuations occur between 2010 and 2020, reflecting variations in ICT investment and connectivity. A significant surge occurs after 2020, showing rapid digital growth driven by increased broadband adoption, mobile access, and digital transformation policies.

Table 3.1: Correlation between Internet users and digital infrastructure

	DII	INTERNET USERS
DII	1.000000	0.865426
INTERNET USERS	0.865426	1.000000

Source: EViews

The table above shows a strong positive correlation (0.865) between Internet users and the Digital Infrastructure Index (DII). As the number of Internet users increases, the level of digital infrastructure development also rises significantly, indicating that internet adoption is a key driver of Nigeria's digital growth.

i. Stationarity tests (unit root)

Table 3.2: Augmented Dickey-Fuller (ADF) Unit Root Test on DII

		t-Statistic	Prob
Augmented Dicker-Fuller	**test statistic**	0.066040	0.9953
Test critical values	**1% level**	-4.309824	
	5% level	-3.574244	
	10% level	-3.221728	

Source: EViews

The table above highlights the results of the Augmented Dickey-Fuller (ADF) unit root test for the Digital Infrastructure Index (DII). The test statistic value of 0.0660 and a high p-value of 0.9953 indicate

that the DII series is non-stationary at its current level, meaning its mean and variance change over time. The critical values at 1%, 5%, and 10% significance levels (-4.31, -3.57, and -3.22) are all lower than the test statistic, confirming that the DII requires differencing to become stationary for time series analysis.

Table 3.3: The regression output for the DII

Variable	Coefficient	Std.Error	t-Statistic	Prob
DII(-1)	0.018884	0.285942	0.66040	0.9479
D(DII(-1))	-0.0914812	0.396150	-2.309256	0.0295
C	-2.892365	5.490751	-0.526770	0.6030
@TREND("1994")	0.479241	0.639691	0.749176	0.4607

Source: EViews

The table above highlights the results of the regression output for the Digital Infrastructure Index (DII). The lagged value of DII, DII(-1), has a positive but statistically insignificant coefficient (p = 0.9479), implying a weak influence from its past values. The first-differenced term, D(DII(-1)), is negative and significant (p = 0.0295), indicating short-term adjustments or fluctuations in DII over time. The constant (C) and trend terms are also insignificant, suggesting that there is no clear deterministic trend driving DII growth.

Table 3.4: Augmented Dickey-Fuller (ADF) Unit Root Test on GDP_Constant

		T	T-statistic	P Prob.
AAugmented Dicker-Fuller	test statistic		-0.970356	0.5924
T Test critical values	1 1% level		-4.309824	
	5 5 % level		-3.574244	
	1 10% level		-3.221728	

Source: EViews

The table above highlights the results of the Augmented Dickey-Fuller (ADF) unit root test for GDP (Constant). The test statistic of -1.9704 is greater than the critical values at the 1%, 5%, and 10% significance levels, and the p-value (0.5924) is well above 0.05. This means the null hypothesis of a unit root to be rejected, is not important, hence, indicating that GDP in its current form is non-stationary.

Table 3.5: The regression output for GDP (Constant)

Variable	Co Co-efficient	Std.Error	t-S t-statistic	Pr Prob.
GDP_Constant_(-1)	-0. -0.139171	0.070632	-1.970356	0.0600
D(GDP_Constant_(-1))	0.530775	0.158540	3.347888	0.0026
C	20.214597	74.333616	2.7 19349	0.0117
@TREND("1994")	22 3.5631	1.154494	1.936460	0.0642

Source: EViews

The table above highlights the regression output for GDP (Constant). The lagged GDP value,

GDP_Constant(-1), has a negative coefficient (-0.0139) but is statistically insignificant (p = 0.0600), suggesting weak long-term dependence on past GDP levels. The differenced term, D(GDP_Constant(-1)), is positive and highly significant (p = 0.0026), indicating strong short-term growth effects. The constant (C) and trend terms are also significant, implying that GDP shows an upward trend over time. The results suggest that while GDP exhibits short-term fluctuations and a general growth trend, it lacks long-term stationarity at the level.

Table 3.6: Augmented Dickey-Fuller (ADF) Unit Root Test on GDP_growth

		Statistic	Prob
Augmented Dicker-Fuller	**test statistic**	.243160	0.0954
Test critical values	**1% level**	-4.296729	
	5% level	-3.568379	
	10% level	-3.218382	

Source: EViews

The table above highlights the results of the Augmented Dickey-Fuller (ADF) unit root test for GDP growth. The test statistic of -3.2432 is less negative than the 5% critical value (-3.5684) but more negative than the 10% level (-3.2184). With a p-value of 0.0954, the result is marginally significant at the 10% level of significance. This suggests that GDP growth is weakly stationary and does not exhibit strong trends or unit root behavior. The growth series is relatively stable over time and can be treated as stationary for the purposes of econometric analysis.

Table 3.7: Regression results for GDP growth

Variable	Coefficient	Std.Error	t-Statistic	Prob
GDP_growth_(-1)	-0.474238	0.146227	-3.243160	0.0031
C	20214597	1.319225	2.590633	0.0153
@TREND(“1994”)	2235631	0.060987	-1.264773	0.2168

Source: EViews

The table above highlights the regression results for GDP growth. The lagged term, GDP_growth(-1), has a negative and statistically significant coefficient (-0.4742, p = 0.0031), indicating that past GDP growth has a dampening effect on current growth, consistent with mean reversion. The constant (C) is positive and significant (p = 0.0153), showing a general upward trend in growth over time. The trend term is negative but statistically insignificant (p = 0.2168), suggesting that there is no strong deterministic trend in GDP growth. The results imply short-term stability and a tendency for growth rates to adjust over time.

Table 3.8: Augmented Dickey-Fuller (ADF) Unit Root Test on Internet users

		t-Statistic	Prob
Augmented Dicker-Fuller	**test statistic**	-1.808546	0.6753
Test critical values	**1% level**	-4.296729	
	5% level	-3. 568379	
	10% level	-3.218382	

Variable	Coefficient	Std.Error	t-Statistic	Prob
INTERNETUSERS_POP_(-1)	-0.197104	0.108985	-1.808546	0.0817
	-0.010140	0.019560	-0.518386	0.6084
@TREND("1994")	0.003898	0.002126	1.833987	0.0777

Source: EViews

The table above highlights the Augmented Dickey-Fuller (ADF) test results for Internet users in Nigeria. The test statistic of -1.8085 and p-value of 0.6753 indicate that the series is non-stationary, as the value exceeds the critical thresholds at all significance levels. The regression output shows that the lagged term INTERNETUSERS_POP(-1) is insignificant (p = 0.0817), suggesting weak dependence on past values, while the trend term is positive but also insignificant (p = 0.0777). This means internet usage has been increasing over time, but with non-stationary characteristics.

Table 3.9: Augmented Dickey-Fuller (ADF) Unit Root Test on Kpi Training

		t-Statistic	Prob
Augmented Dicker-Fuller	**test statistic**	-4.375191	0.0083
Test critical values	**1% level**	-4.296729	
	5% level	-3.568379	
	10% level	-3.218382	

Variable	Coefficient	Std.Error	t-Statistic	Prob
KPI_TRAINING(-1)	-0.808642	0.184824	- 4.375951	0.00002
C	8.636822	0.199059	3.927507	0.0005
@TREND("1994")	-0.134881	0.067165	-2.008196	0.0547

Source: EViews

The table above highlights the Augmented Dickey-Fuller (ADF) test results for KPI Training. The test statistic of -4.3752 is lower than all the critical values at the 1%, 5%, and 10% significance levels, with a p-value of 0.0083, indicating that the series is stationary at the level. The regression output shows a highly significant lagged term (p = 0.00002) and a positive constant, suggesting consistent performance improvements over time. The trend term is negative but weakly significant (p = 0.0547), implying a slight decline in trend.

Table 3.10: Augmented Dickey-Fuller (ADF) Unit Root Test on Fixed broadband

		t-Statistic	Prob
Augmented Dicker-Fuller	**test statistic**	- 0.175391	0.9907
Test critical values	**1% level**	-4.296729	
	5% level	-3.568379	
	10% level	-3.218382	

Variable	Coefficient	Std.Error	t-Statistic	Prob

Fixedbroadband_100_ (- 1)	-2.435643	13.88692	-0.175391	0.8621
C	-0.476303	0.477894	-0.996672	0.3278
@TREND("1994")	0.048917	0.038506	1.270387	0.2148 [1

Source: EViews

The table above highlights the Augmented Dickey-Fuller (ADF) test results for Fixed Broadband. The test statistic of -0.1754 with a p-value of 0.9907 is far above all critical values, indicating that the series is non-stationary. This means broadband data fluctuates over time without a stable mean or variance. The regression results show that the lagged term (Fixedbroadband_100_(-1)) and trend components are statistically insignificant, suggesting no meaningful short- or long-term stability. The Fixed Broadband series exhibits strong upward trends typical of technological adoption data.

(ii). JOHANSEN COINTEGRATION TEST

Table 3.11 Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized – No of CE(s)	**Eigenvalue**	**Max-Eigen Statistics**	**0.05 Critical Value**	**Prob**
None	0.427742	16.74497	27.58434	0.6019
At most 1	0.188427	6.263434	21.13162	0.9771
At most 2	0.119579	3.820653	14.26460	0.8778
At most 3	0.001827	0.054869	3.841465	0.8148

Source: EViews

Table 3.12: Unrestricted Cointegration Coefficient (normalized by b*S11*b=1)

INTERNET USERS	**FIXEDBROADCAST**	**KPI_TRAINING**	**DII**
-0.721488	-1.555282	0.337273	0.037270
-2.154909	20.63236	0.078328	-0.046537
-16.41042	35.11126	0.049891	0.110626
-1.883528	-57.43827	-0.020913	0.055056

Source: EViews

Table 3.13: Unrestricted Adjustment Coefficients (alpha)

D(INTERNET USERS)	1.91E-05	0.001973	0.002885	0.001903
D(FIXEDBROADCAST)	0.033943	-0.394384	0.276792	0.006159
D(KPI_TRAINING)	-2.328603	-0.293734	-0.110626	0.007854
D(DII)	0.944759	-2.947369	1.248333	0.1833507

Source: EViews

The table above highlights the Johansen cointegration test results examining the long-run relationship among Internet users, Fixed Broadband, KPI Training, and the Digital Infrastructure Index (DII). The Maximum Eigenvalue test shows all p-values above 0.05, meaning there is no significant cointegration among the variables—thus, no stable long-term equilibrium relationship exists. The cointegration coefficients indicate the direction and relative strength of relationships among variables, while the adjustment coefficients (alpha) show how quickly each variable responds to short-term disequilibrium. The results suggest that digital infrastructure components in Nigeria move independently in the long run but may interact in the short run.

Table 3.14: Vector Error Correction Estimates

Cointegrating Eq	CointEq1
INTERNET USERS	1.000000
FIXED BROADBAND	1.708348
	(8.50248)
	{0.20092}
KPI TRAINING	0.133716
	(0.04482)
	{2.98352}
DII(-1)	-0.018917
	(0.01046)
	{-1.80812}
C	-0.952237

Source: EViews

The table above highlights the Vector Error Correction Model (VECM) cointegrating equation, which represents the long-run equilibrium relationship among Internet users, Fixed Broadband, KPI Training, and the Digital Infrastructure Index (DII). The coefficient for Fixed Broadband (1.7083) is positive and significant, indicating that improvements in broadband access strongly enhance digital infrastructure. KPI Training (0.1337) also shows a positive and significant impact, implying that capacity building supports digital growth. The negative coefficient for DII(-1) (-0.0189) suggests a mild adjustment toward equilibrium when deviations occur. The model indicates that broadband development and training are key long-term drivers of digital infrastructure in Nigeria.

Table 3.15: The Vector Error Correction Model (VECM) short-run dynamics

Error Correction	D(INTERNET US USERS)	D(FIXED BROADBAND)	D(FIXEDzzzzzzzzz	D (KPI_TRAINING)	D(DII)	D(DII)
CointEq1	-0.018513	-1.154253	-1.154253	-4.665541	-4.665541	-8.044631	-8.044631
	(0.01633)	(0.66169)	(0.66169)	(1.58389)	(1.58389)	(4.27221)	(4.27221)
	{-1.13359}	{-1.13359}	{-1.74440}	{-1.74440}	{-2.94563}	{-2.94563}	{-1.88302}	{-1.88302}
D(INTERNETUSERS(-1)	0.932053	12.801982	12.80198	6.398898	6.398898	125.5708	125.5708
	(0.23048)	(0.23048)	(9.33827)	(9.33827)	(22.3529)	(22.3529)	(60.2924)	(60.2924)
	{4.04394}	{4.04394}	{1.37176}	{1.37176}	{0.28627}	{0.28627}	{2.08270}	{2.08270}
D(INTERNETUSERS(-2)	-0.282865	-0.282865	-5.736240	-5.736240	36.80496	36.80496	-67.11037	-67.11037
	(0.25399)	(0.25399)	(10.2907)	(10.2907)	(24.6327)	(24.6327)	(66.4417)	(66.4417)
	{-1.11369}	{-1.11369}	{-0.55742}	{-0.55742}	{1.49415}	{1.49415}	{-1.01006}	{-1.01006}
D(FIXEDBROADBAND(-1)	-0.146475	-0.146475	14.31248	14.31248	23.45552	23.45552	38.60618	38.60618
	(0.35474)	(0.35474)	(14.3728)	(14.3728)	(34.4039)	(34.4039)	(92.7976)	(92.7976)
	{-0.49291}	{-0.49291}	{0.99581}	{0.99581}	{0.68177}	{0.68177}	{0.41603}	{0.41603}
D(FIXEDBROADBAND(-2)	1.250676	1.250676	5.829787	5.829787	7.641377	7.641377	97.52455	97.52455
	(0.38197)	(0.38197)	(15.4761)	(15.4761)	(37.0450)	(37.0450)	(99.9212)	(99.9212)
	{3.27426}	{3.27426}	{ 0.37670}	{ 0.37670}	{0.20627}	{0.20627}	{0.97601}	{0.97601}
D (KPI_TRAINING(-1)	0.003438	0.003438	0.102044	0.102044	-0.086432	-0.086432	0.994322	0.994322
	(0.00233)	(0.00233)		(0.09460)		(0.22645)		(0.61081)
		{1.72096}		{1.07863}		{-0.38167}		{1.62786}
D	D(KPI_TRAINING(-2)	0.003512		0.083904		0.236909		0.869463
		(0.00204)		(0.08269)		(0.19793)		(0.53389)
		{1.72096}		{1.01468}		{1.19690}		{1.62855}

D	D (DII(-1)	-0.007412	-0.472984	-0.472984	-1.453455
		(0.00258)	(0.24990)	(0.24990)	(0.24990)
		{-2.87665}	{11.89273}	{-1.89273}	{-2.15633}
D	D (DII(-2)	0.002674	0.052825	-0. 654488	0.779366
		(0.00310)	(0.12579)	(0.30109)	(0.81213)
		{1.86136}	{0.41996}	{-2.17372}	{0.95965}
	C	0.014558	0.339478	1.332618	3.889477
		(0.00891)	(0.36094)	(0.86398)	(2.33042)
		{1.63420}	{0.94053}	{1.54241}	{1.66900}

Source: EViews

The table above presents the Vector Error Correction Model (VECM) short-run dynamics, showing how deviations from long-run equilibrium are corrected over time. The error correction term (CointEq1) is negative across all dependent variables, indicating convergence toward equilibrium, with the strongest adjustment seen in KPI Training (-4.6655) and DII (-8.0446). The lagged variables reveal that Internet users (-1) and Fixed broadband (-2) significantly and positively influence digital infrastructure (DII), suggesting that past growth in connectivity stimulates future digital development. The negative coefficients for DII(-1) imply that deviations in digital infrastructure adjust slowly. The results suggest a stable short-run adjustment process, where internet usage, broadband expansion, and training efforts collectively drive long-term growth in digital infrastructure.

4.0 DISCUSSION OF FINDINGS

There was a shift from minimal digital involvement to the internet, followed by an expansion of broadband penetration and then rapid digital growth driven by increased broadband adoption, mobile access, and digital transformation policies. The DII series is non-stationary at its current level, meaning its mean and variance change over time. This means that internet adoption is a key driver of Nigeria's digital growth. Fluctuations suggested that there is no clear deterministic trend driving DII growth. In its current form, GDP is non-stationary, exhibits short-term fluctuations and a general growth trend, and finally lacks long-run stationarity at levels. The absence of a strong deterministic trend in GDP growth implies short-term stability and a tendency for growth rates to adjust over time. Digital infrastructure components in Nigeria tend to operate independently in the long run but may interact in the short term. Improvements in broadband access significantly enhance digital infrastructure, and the positive and significant impact of KPI training implies that capacity building supports digital growth. VECM indicates that broadband development and training are key long-term drivers of digital infrastructure in Nigeria. In conclusion, the results suggest a stable short-term adjustment process, where internet usage, broadband expansion, and training efforts collectively drive long-term growth in digital infrastructure. Backtracking to section two, that's fully on the literature review, empirically, Donatus et al 2024 concluded that, businesses should adopt mobile telecommunication networks to exchange messages between the nodes and provide cell service and related services to mobile phones users, and; Norris, 2020 decided about, governments, organizations, and communities collaborating to ensure everyone has access to the necessary digital tools and skills to participate in the digital economy and society.

5.0 CONCLUSION AND EXPECTED POLICY IMPLICATION

The study's outcome will help policymakers, as well as related government ministries, departments, and agencies. The inclusivity of females, the less privileged, and effective management for the underaged

through digital transformation policies would not only bring in a substantial amount of income to the government but also place the country on a growing pedestal in the global world. The internet users, fixed broadband, and digital infrastructure index were components analysed. Still, the youth population and those of working age can also be trained formally or informally. Nigeria's influx of tech institutes, such as Udemy, LinkedIn Learning, Tech360, and ALX Tech, among others, has led to a positive increase in the number of data scientists, virtual assistants, and content creators. I'll repeat that capacity building supports digital growth. A significant surge of the digital infrastructure index (DII) occurs after 2020, showing rapid digital growth driven by increased broadband adoption, mobile access, and digital transformation policies. The current government has decided to start taxing content creators, ensuring that it's not just physical work that leads to income tax. In a humorous yet important situation, Miss ImisiOluwa, who won the recently concluded Big Brother Naija (BBN) reality show, would be taxed on her prize money; hence, any digital source of income would contribute to the country's major source of revenue, taxation.

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Assessing Policies for Promoting Food and Nutrition Security in Nigeria

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1. Background

The United Nations, in 2015, adopted the Sustainable Development Goals (SDGs) as a "blueprint for a better future". Goal 2 of the SDGs ambitiously aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. Specifically, SDG target 2.2 seeks to end all forms of malnutrition, reduce stunting and wasting among under-five children, and address the nutritional needs of adolescent girls, pregnant and lactating women, and elderly persons (United Nations, 2024a). According to the 1996 World Food Summit, food security exists when *"all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (*George-André, 2012, p.4*).* Almost ten years after adopting the SDGs, more than 864 million people (10.7% of the global population) are facing severe food insecurity - 310 million more people than in 2015 (FAO et al 2024). FAO et al (2024) further revealed that an additional 2.33 billion (28.9%) are severely or moderately food-deprived globally in 2023. World Bank (2024) is projecting that the severely food-insecure population will reach 956 million by 2028. The global food security crisis has been accentuated by the global poly crises - COVID-19, Russia-Ukraine war, climate change, global supply chain disruption, conflicts, and record high inflation (United Nations, 2024b).

In Nigeria, like the rest of the world, food and nutritional insecurity has worsened. According to FMARD (2016), Nigeria accounted for 5% of the global burden of undernutrition with over 14 million undernourished children. Similarly, the United Nations Children's Fund (UNICEF, 2023) noted that about 25 million Nigerians are at risk of food insecurity in 2023, up from the 17 million people who were food-insecure in 2022. FAO et al (2024) also equally that the number of Nigerians who are severely food insecure more than doubled from 20.3 million between 2014 and 2016 to 49.4 million (22.6% of the population) between 2021 and 2023; and an additional 112 million people (51% of the population) are moderately food insecure between 2021 and 2023. Forecasts by the United Nations suggest that it could reach about 82 million Nigerians (64%) by 2030 (Akasike & Adaji, 2024). The bulk of the food-insecure population are in the North-East and North-West regions and include internally displaced persons because of conflicts. There is also a wide gap in food insecurity between rural and urban areas.

The food security situation in Nigeria is relatively serious compared to other countries. According to Global Food Security Index 2022 (Economist Intelligence Unit (EIU), 2022), Nigeria ranks

[1] *This is a work-in-progress paper that is being prepared for the 2025 NAMM Conference. Please do not cite. For any information on the paper, kindly contact the corresponding author.*

107th out of 113 countries on food security in 2022. Similarly, out of 28 sub-Saharan African countries, Nigeria ranks 25th with an overall score of 42 points. South Africa topped the sub Saharan ranking with a

score of 61.7 points, followed by Kenya (53 points) and Ghana (52.6 points).

The problem of food insecurity is translated to a public health challenge through inadequate food consumption and poor diets, reflecting in malnutrition and other related issues. FAO et al (2024) documents that 39.4 million Nigerians (or 18% of the population) do not have access to enough food to meet their daily energy requirements. About 9 million Nigerian children are estimated to be at risk of acute malnutrition or wasting, and 29% of these children could face Severe Acute Malnutrition (FAO, OCHA and UNICEF, 2023). Although Nigeria's undernourishment prevalence rate of 18% is below the sub-Saharan Africa average of 22.7%, 1 out of every 7 undernourished persons in the sub-region lives in Nigeria. Some of the SSA countries with high prevalence rates include Kenya (34.5%), Angola (23.2%), Ethiopia (22.2%), and Central African Republic (23.5%) among others. Interestingly, some SSA states like Ghana (6.2%) and South Africa (8.1%) have relatively lower prevalence rates. Poor diets are also associated with non communicable diseases such as cancer, obesity, high blood pressure and heart diseases.

If unchecked, the current trend could substantially undermine the goal of achieving sustainable food and nutritional security by 2030. Food and nutritional insecurity pose significant public health and development challenges for the country, undermining human capital development and contributing to economic losses. The Nigerian government declared a state of emergency on food security in mid-2023. However, confronting the multidimensional challenges of food and nutritional insecurity requires a holistic policy approach. This is the goal of this study. The study examines and simulates policy options that can help to achieve food and nutritional security in Nigeria.

To address this challenge, the Nigerian government has formulated several policies, focusing on agricultural productivity, income support, education awareness, cash transfers and health interventions (see Appendix for overview of these policies). On the one hand, the National Food Security Program (NFSP), Agricultural Transformation Agenda (ATA), the Anchor Borrowers' Program (ABP), Agricultural Sector Food Security and Nutrition Strategy (ASFSNS) are key food security programmes focusing on agriculture-related interventions. On the other hand, the National Policy on Food and Nutrition (NPFN), National Plan of Action on Food and Nutrition, National Social Investment Programme (NSIP), National Strategic Plan of Action for Nutrition (NSPAN) and National Multi-Sectoral Plan of Action for Food and Nutrition, in addition to promoting agricultural productivity, focus on non-agriculture related interventions such as school feeding programme, cash transfer, nutrition education and awareness, micronutrient supplementation, pricing policy, etc. Despite these policies, food and nutrition security outcomes continue to worsen, raising questions about the effectiveness and impacts of these policy interventions.

Several studies have been conducted on the effectiveness and impact of policy interventions on food and nutrition security in Nigeria. While studies like Donkor, et al. (2017) and Awotide, et al. (2013) examine agriculture-focused interventions, Ogunsile and Ogundele (2016), Babatunde and Olagunju (2020) and Okeke and Abubakar (2020) focus on the effect of non-agriculture related interventions such as nutrition education, cash and food transfers on food and nutrition security. However, most of these studies adopt a micro approach and fail to consider general equilibrium or feedback effects. For instance, the studies did not consider the possibilities of price or economic factors influencing food consumption choices and ultimately food and nutrition security. In addition, these policy interventions are examined independently, and there is no known study that has evaluated and compared the impacts of different policies with a view to ascertaining the optimal policy option(s) for enhancing food and nutrition security in Nigeria. While existing studies analyse the impact of specific policies, there is limited information on how the effect of one policy differs from another. These are the main gaps this study aims to fill.

This study aims to understand the food consumption patterns in Nigeria and simulate and compare the impacts of different policies on economic and food and nutrition security indicators. The research questions this study aims to answer are as follows:

(i) What are the food consumption patterns of Nigerian households, and do these patterns differ based on region, rural-urban and income level?

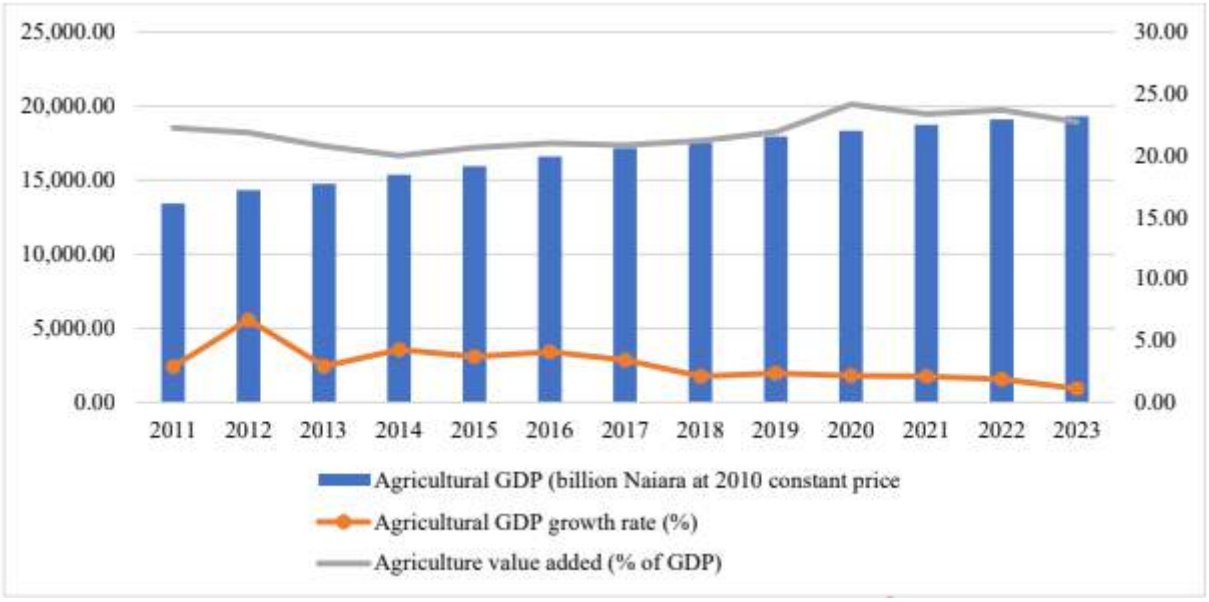
(ii) What are the economy-wide and food and nutrition impacts of policy interventions to enhance food and nutrition security?

2. Dimensions of food security: Understanding the form and drivers of food and nutrition security in Nigeria

Nigeria has had a foretaste of myriad crises, ranging from external shocks and spillovers (such as COVID-19 pandemic, the Russia-Ukraine war) to domestic challenges (including worsening insecurity, climate change and macroeconomic instability). These crises, which are not mutually exclusive, disrupt food production, supply chains, and affordability, leading to increased food shortages and malnutrition among the population. The challenges of food and nutritional security in Nigeria is discussed within the context of the four dimensions of food security: availability, affordability, stability and utilization.

The first dimension of food security, availability, is related to the supply of food to meet the demand. In Nigeria, agricultural productivity has increased over the years, but still inadequate to meet local demand. As shown in Figure 1, agriculture output (agriculture GDP) increased steadily from increased from N13,429.38 billion in 2011 to N19,306.49 billion in 2023. However, the growth rate of agricultural GDP has declined from the peak level of 6.70% in 2012 to 4.11% in 2016, 2.36% in 2019 and 1.13% in 2023. The steady in the growth rate of agricultural GDP. Meanwhile, agriculture value added as a % of GDP has held steady from 22.22% in 2011 to 22.7% in 2023. The slow growth in the performance of the sector reflects the weak productivity in the sector and its abilities to meet the food supply for the local population. According to FAO (2022), 70% of Nigerians are involved in the agricultural sector, but agricultural productivity and crop yields have remained low due to the subsistence nature of agriculture in Nigeria.

Figure 1: Agriculture productivity indicators



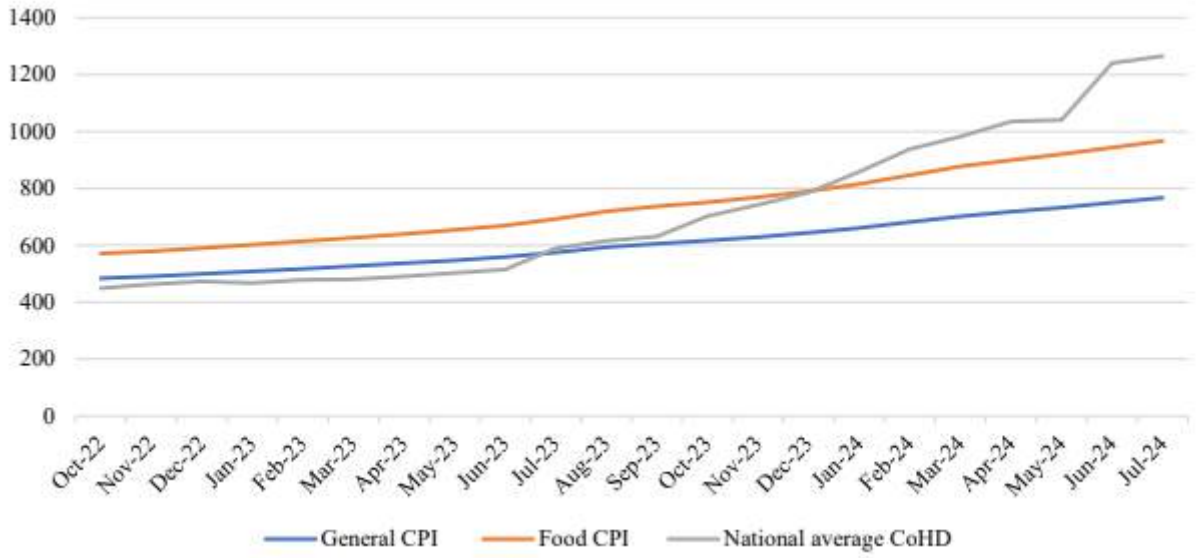
Source: Data from Central Bank of Nigeria Statistical Bulletin and World Development Indicators of the World Bank

Food availability in Nigeria, especially with respect to production, is undermined by several factors. For example, heightened security challenges, particularly in the Northeast, have disrupted agricultural activities. GAIN (2022a) estimates that about 2.13 million farmers are displaced in the Northeast alone. Gavin (2023) reports that a cumulative of about 98,000 persons have been killed by non-state actors (including Boko Haram, Bandits, sectarian and other armed actors) since 2012. With farmers not being able to access their farms or transport their farm produce to markets due to threats from insurgent groups, the availability dimension of food and nutritional security is significantly undermined. This also aggravates the problem of post-harvest losses in Nigeria, which is as high as 50% for fresh fruits and vegetables (GAINS, 2022b). The monetary value of the post-harvest losses is estimated at N3.5 trillion (Olawoyin, et al., 2024), higher than the combined imports and exports of agricultural commodities, and more than triple the annual government budget for the agriculture sector.

Other crises that affected the availability dimension include climate change and the COVID-19 pandemic. Nigeria is experiencing extreme weather events (such as droughts and floods) resulting in crop failures, reduced yields, and food shortages, thereby exacerbating food insecurity. The existing vulnerability in the Nigerian food system was exacerbated by the COVID-19 pandemic. Lockdowns and movement restrictions hindered agricultural activities, and disrupted supply chains, leading to food shortages and price hikes (Dauda, 2023, Nicholas-Okpara et al., 2023).

The second dimension of food security is access, which is related to physical and economic access to food. Having adequate food production or availability is insufficient to guarantee food security as poor infrastructure, high prices, low income, etc. could undermine the translation of food production into access for households. For instance, Nigeria's headline inflation has trended above the central bank's upper bound target of 9% for over ten years. As of October 2024, the headline food inflation rate was 39.16% (NBS, 2024a). Spiraling inflation erodes the purchasing power of individuals, making food less affordable for many low-income households. The inflationary pressure was heightened by massive currency depreciation. The naira has depreciated by over 100% since 2023. Exchange rate volatility does not only affect imported food prices but also domestic food prices through both adjustment and export effects. Low productivity and tepid economic growth reduce income, further limiting the affordability of a diverse and balanced diet. As shown in Figure 2 below, the cost of a healthy diet (CoHD) has almost tripled from N449 in October 2022 to N1,265 in July 2024.

Figure 2: Consumer price index and cost of healthy diets, October 2022 – July 2024



Source: National Bureau of Statistics

The third dimension, utilization, has to do with how the body metabolizes food and utilizes the nutrients in the food consumed. Merely having access to food is insufficient in combating food insecurity if individuals do not metabolize it efficiently due to factors like lack of nutrition knowledge, unhealthy eating habits, or health issues. As observed by Mumed et al (2023), citizen's education, healthcare provisions and income level are critical for achieving the utilization dimension. In the case of Nigeria, the prevalence of wasting is 6.5% as of 2020, but about 12 million Nigerian children are affected by stunting. Although there has been progress in reducing the prevalence of stunting from 42% in 2000 to 34.2% in 2022, the current level is still higher than the African average. Based on the 2021 National Food Consumption and Micronutrient Survey, the dietary patterns of children in urban areas are suggestive of being unhealthy and obesogenic (FGoN & IITA, 2024). Meanwhile, the incidence of non-communicable diseases such as cancer, diabetes and hypertension has also been rising. 17% of adult Nigerian women were estimated to be obese in 2022, double the level in 2005 (Phelps et al., 2024).

In addition, the necessary infrastructure required to ensure that people get maximum nutrition for food consumed are not fully in place. According to the Multiple Indicator Cluster Survey (MICS), access to basic drinking water, sanitation and hygiene in Nigeria is 72%, 38% and 29% respectively. The access rate is even much lower for rural areas at 57%, 28% and 22% respectively. Without commensurate improvement in these complementary services, the utilisation dimension of food security is compromised.

The last dimension of food security has to do with stability of the other three dimensions over time. This means that availability, access and utilization of food must always be stable, and not

susceptible to the impacts of exogenous factors (Manikas et al., 2023) To be considered as food and nutritionally secure, there must be a guarantee of smoothened food and nutritional intake over time (WHO, 2023). The food system is prone to several factors that could affect the status of households. For instance, poor weather conditions, political instability, economic instability and conflicts can have negative effects on the stability and sustainability of the food systems. Weak infrastructure, transportation challenges, and market inefficiencies can result in food supply disruptions. Political instability and conflicts can disrupt food production, distribution, and access. The current security situation in Nigeria adversely affects the production and distribution of food, contributing to increase

in prices. Extreme weather conditions in recent years also affect agricultural productivity, resulting in crop damage and farm losses. The current macroeconomic challenges in the country, with poverty and unemployment levels rising, also undermine the stability of food intake for households.

3. Review of relevant literature: Impact assessment of policy interventions for enhancing food and nutritional security in Nigeria

Several studies have been conducted on the impact of public policy intervention on food and nutrition security in Nigeria. Some of these studies focus on interventions to enhance agricultural productivity. For instance, Donkor, et al. (2017) examines the effect of the Presidential Cassava Initiative on cassava production and food security in Nigeria using a three-stage multivariate linear regression model. The Initiative is a cross-country initiative (Nigeria, Ghana and DR Congo), and the intervention focuses on cassava production and processing development, and marketing of processed cassava. The results of the analysis show that the Initiative leads to an increase in cassava production and enhances national food supply and food security. Awotide, et al. (2013) analyses the impact of seed vouchers on poverty reduction among rice farmers in Nigeria. This is implemented alongside the USAID-funded Emergency Rice Initiative to boost rice production. The study uses randomized control trials to provide subsidised improved rice seeds to selected farmers. Using the inverse propensity score weighing (IPSW) and the local average treatment effect (LATE) estimation techniques, the study finds that the seed voucher system has a positive and significant impact on household income and per capita consumption expenditure.

Additional studies focus on the effect of interventions to enhance nutrition and healthy diets. One of such studies is Ogunsile and Ogundele (2016). The study analyses the effect of game-enhanced nutrition education on knowledge, attitude and practice of healthy eating among adolescents in Ibadan city of Nigeria. Using questionnaires to collect data and ANCOVA to analyse the data, the study finds that nutrition education has a significant effect on knowledge, attitude and practice of healthy eating in Nigeria. Ogbo, et al. (2017) analyse the effect of government policy responses for improving infant and young child feeding practices in Nigeria. Focusing on the Baby Friendly Hospital Initiative and the National Breastfeeding Policy, the study uses data from the Nigeria Demographic and Health Surveys from 1999 to 2013. The data is used to calculate prevalence rates, taking cognizance of the cluster sampling design. The study shows that the policy responses have not had significant positive impact on infant and children feeding practices. Specifically, the analysis shows that early initiation of breastfeeding decreased significantly by 4.3%; while exclusive breastfeeding remained unchanged. Minimum meal frequency also increased significantly by 13.8% while minimum dietary diversity and minimum acceptable decreased by 9.7%. Lastly, predominant breastfeeding increased by 13.1% while children ever breastfed by 16.4%. Babatunde and Olagunju (2020) examine the relative effects of cash and food transfer as an effective response mechanism against food insecurity during COVID-19 pandemic. Using phone survey data, they find that cash transfer is more effective than food assistance in improving food consumption and dietary diversity.

Further studies have gone to examine the effectiveness of social safety nets on food security, nutrition and health in Nigeria. Okeke and Abubakar (2020) examine the effect of cash transfer conditioned on mother's health care utilization during pregnancy on child health. They find that the cash transfer leads to an increase in the uptake of formal maternal healthcare services during pregnancy while also resulting in significant reductions in child mortality.

The review of the literature shows that there are several studies that have analysed the impacts of specific interventions on food and nutrition security indicators in Nigeria. However, there is no known

study that has evaluated and compared the impacts of different policies with a view to ascertaining the optimal policy option(s) for enhancing food and nutrition security in Nigeria. In other words, while existing studies analyse the impact of specific policies, there is limited information on how the effect of one policy differs from another. This is the main gap this study aims to fill. In addition to the food and nutrition security indicators, the study also assesses the economic impact of food and nutrition policies.

4. Method

We use two different but complementary approaches to answer the research questions. For the first research objective which aims to analyse the food consumption patterns of Nigerian households, we analyse data from the Living Standard Measurement Survey 2018/2019. This survey contains data on food consumption of over 22,000 representative Nigerian households. From the data in the survey, the nutrient contents of the food consumed are estimated. This allows us to analyse consumption of different food groups, diet quality, and nutrient intakes, across different regions, rural-urban and income quintiles.

For the survey, respondents report on the quantity of food consumed at home across many food categories in a unit of their choice. The quantities consumed are then converted into grams using detailed conversion tables for all non-standard units. The nutrient contents of the food consumed are subsequently derived from information from the 2019 FAO/INFOODS Food Composition Table for West Africa, accounting for the cooking and processing methods. In addition, the respondents report on the amount of food consumed outside the home. For food items consumed away from home, the expenditure and monetary value of consumption of the household is obtained. The calorie contents are estimated by dividing these expenditure by the median value of a calorie derived from consumption at home. Fat, protein and carbohydrates contents are estimated by using an equal share of energy as home consumption. Micronutrient contents are estimates by dividing expenditures by the median value of nutrient derived from consumption at home (Moltedo, et al., 2014; 2018).

Overall, the food categories in the survey are grouped into 16 food groups, and the indicators of diet quality and adequacy include dietary diversity score (HCES-DDS, 0-16), hGDQS (adapted version of the Global Diet Quality Score, 0-45), food gap according to IPC/CH (less than 2100 kcal per day), WHO recommended macronutrient intake proportion (>30% of energy intake derived from fat, <10% of energy intake derived from protein, and <400 grams/AE/day of fruit and vegetables.

For the second research objective, we use the DEMETRA, a single-country, recursive-dynamic, open-economy CGE model, and Nigeria's 2019 social accounting matrix (El Meligi, et al., 2024). The model helps to analyse the economy-wide and food consumption impacts of existing and potential policies. CGE models are useful to analyse economy-wide impacts of public policies and have been widely used to evaluate the impacts of agricultural and food security policies. The policies are simulated using the model to obtain macroeconomic, structural and household (food) consumption impacts. The results of the CGE model are then linked to a micro-model to examine the impacts of these macro changes on food and nutrition indicators, which are based on the food consumption pattern mapped with the survey data. In other words, the changes in food consumption patterns obtained from the results of the CGE model are connected to the diet quality and nutrient intake mapped to each food group based on the Living Standard Measurement Survey 2018/2019 data, which then provides information about how the simulated policies ultimately affect diet and nutrition, beyond only the quantity of food consumed.

The different policy scenarios analysed in this paper is obtained from food and nutrition policy stakeholders in Nigeria at a policy stakeholder engagement workshop. The workshop brought together

government officials (representatives of Ministry of Agriculture and Food Security, Ministry of Health and Social Welfare, Ministry of Budget and National Planning, Office of the Special Adviser to the President on Agriculture, House of Representatives Committee on SDGs, National Agricultural Development Fund), academics, researchers, international organisations (United Nations World Food Programme) and civil society organisations (CSOs) to elicit policy ideas that can help to enhance food and nutrition security.

Following from the engagement, some key policy ideas emerge. Overall, the emerging views focus on the production and consumption sides. Policies to increase food availability are hinged on increasing production levels, reducing on-farm losses, and encouraging small-scale production for own consumption. These policies have to do with improving seed quality, promoting climate resilient agriculture, improving fertiliser quality, and agriculture sector mechanization. Some policy ideas on the demand/consumption side are also noted. The key policy interventions in this regard are nutrition education and behavioural change communication campaigns, income support for low-income households, and improve affordability of nutritious food.

Overall, the following six policy scenarios, which capture both the supply and demand-side of the policy interventions, are adopted.

Policy scenario 1: Increase in the production of key crops such as vegetables, millets, sorghum and other cereals; and rice through improved seed quality, improved fertiliser quality and application, adoption of climate resilient agriculture

Policy scenario 2: Reducing on-farm losses.

Policy scenario 3: Encouraging small-scale production for own consumption. **Policy scenario 4:** Income support for low-income households.

Policy scenario 5: Improve the affordability of nutritious food through price subsidy. **Policy scenario 6:** Nutrition education and behavioral change communication campaigns.

This work in progress report contains the results of two of the policy scenarios (1 and 3) and is based on the static version of the model. Modeling work is ongoing on the remaining scenarios and the dynamic version of the model. Afterwards, the results of the model will be connected with a micro-model to analyse the impact on diet and nutrition indicators.

5. Preliminary results

The preliminary results of the results of the analysis are presented in this section. The first section focuses on the results of the analysis of the food consumption pattern of Nigeria households. The second section presents preliminary results of the CGE modeling.

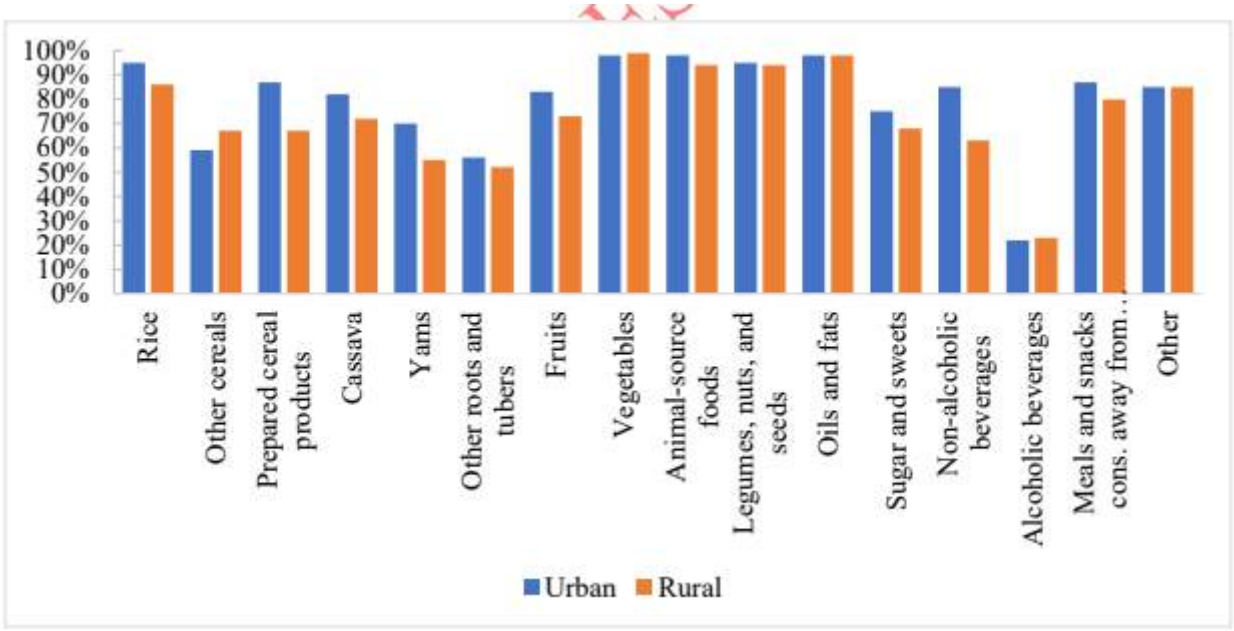
5.1 Consumption pattern and nutrient quality of Nigerian households

The survey shows that majority of Nigerians consume basic food items like rice, vegetables, animal-sourced foods, oils and fats, legumes/nuts/seeds (Figure 3). The consumption of these different food groups also vary between rural and urban households, in most cases with urban households having higher consumption than rural households. 98% of urban households reported consuming vegetables, animal-sourced foods, oil and fats while 95% reported consuming rice, legumes/nuts/seeds. Only 83% of urban households reported consuming fruits. The food groups least consumed by urban households include other cereals (59%), other roots and tuber (56%) and alcoholic beverages (22%).

Vegetables is the most consumed food groups among rural households (99%), marginally higher than urban households (98%). 98% of rural households reported consuming oils and fats while 94%

consumed animal-sourced proteins and legumes/nuts/seeds. 27% of rural households did not consume any fruits. The only food categories where rural households have higher consumption than urban households are other cereals, vegetables, and alcoholic beverages. It is noteworthy that about 87% of urban households and 80% of rural households consume meals and snacks away from home.

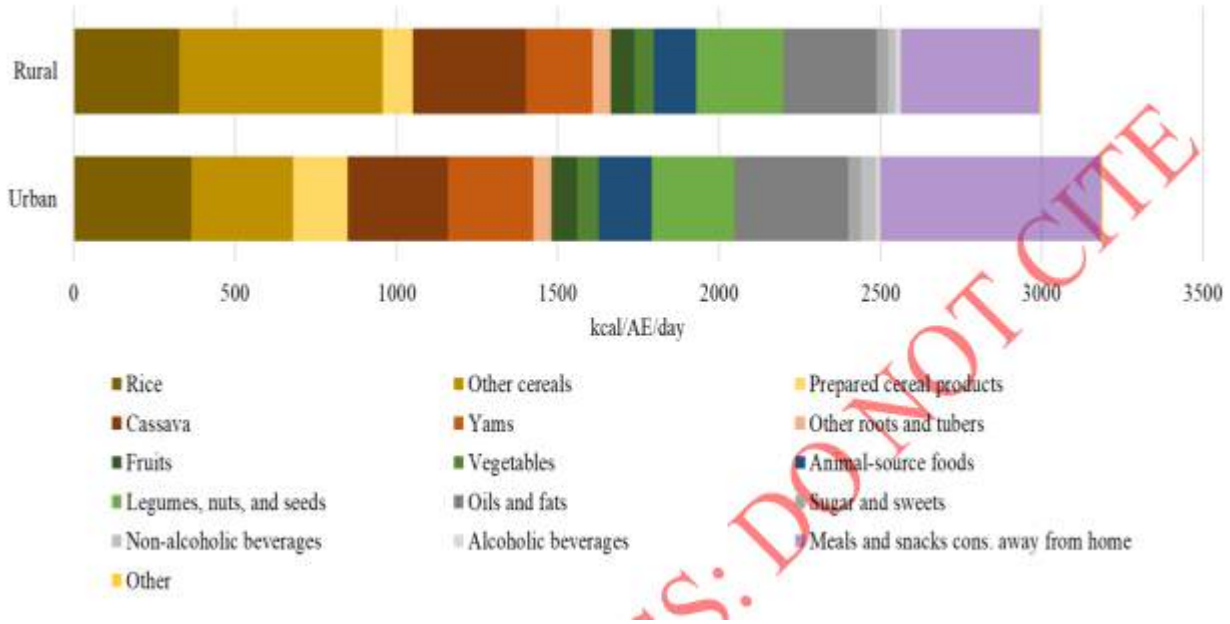
Figure 3: Proportion of households that consume different food groups



Source: Authors' computation

Figure 4 further shows that diets is dominated by staple foods, accounting for 52% of energy intake in urban areas and 56% in rural areas. Meanwhile, consumption of traditional staple cereals such as maize and millets is much lower for urban households. The diets of urban households is also higher in both nutritious food groups (animal-source foods, fruits and vegetables) and unhealthy foods (oils and fats, sugar and sugary drinks). Meals and snacks consumed outside the household are relatively more important food sources for rural households.

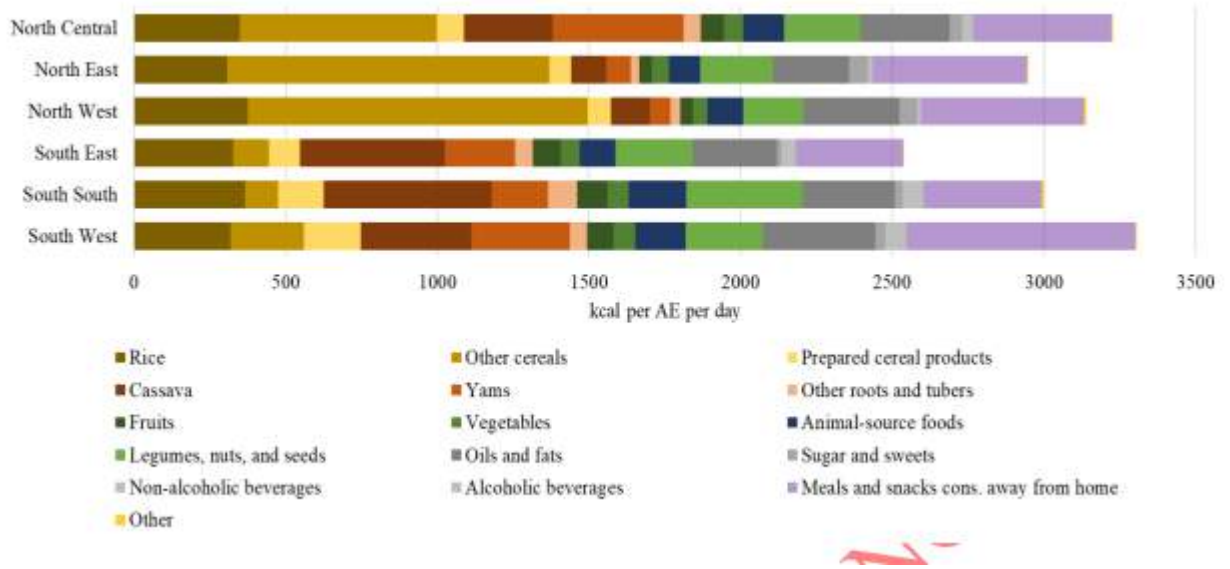
Figure 4: Consumption of different food groups, rural and urban households



Source: Authors' computation

Figure 5 presents the consumption of the different food groups across the six (6) geopolitical zones. Overall, the energy intake of households in the South East is the lowest while that of the South West is the highest. The diet of households in the North (North East, North West and North Central) are mainly dominated by traditional staple foods (cereals, maize, millet and sorghum). Rice and yam are also major sources of food for the North Central region. Staple food accounts for about average 50% of overall energy intake. In the South, yam, cassava and rice are major food sources. Intake of fruit, vegetables and animal-sourced foods are low in the North West and North East.

Figure 5: Consumption of different food groups, by geo-political zones

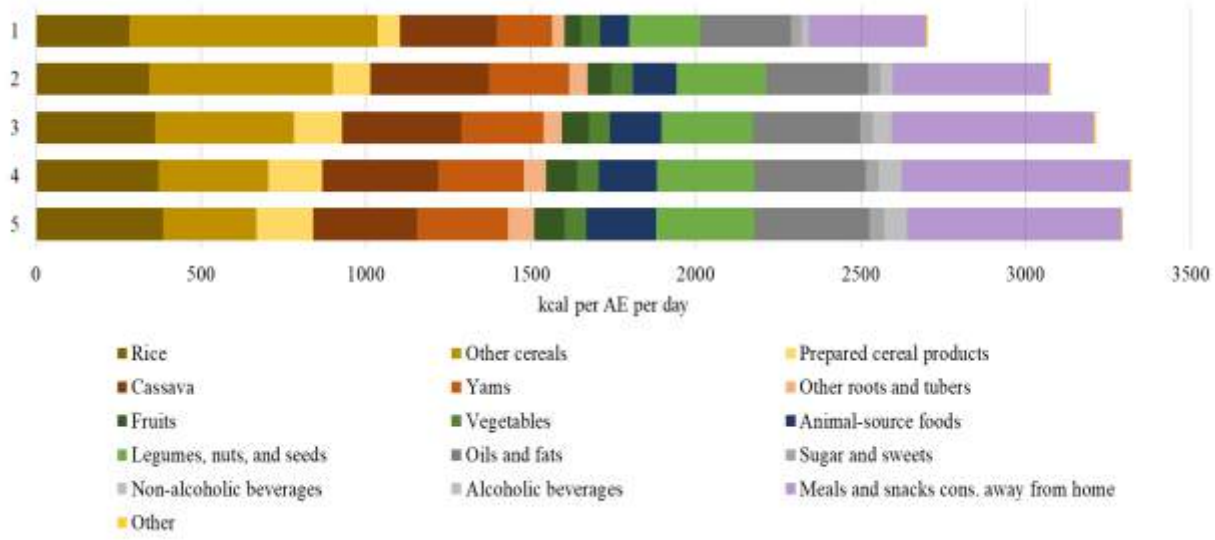


Source: Authors' computation

Figure 6 presents the consumption of the different food groups by income level. As shown by the results, the lowest income quintile group has the lowest energy intake, but the energy intake increases

especially early in the income distribution. Low-income households depend heavily on traditional staple foods, including cassava and yam. However, as the income level increases, the consumption of these food items reduces steadily and consistently, with households shifting consumption towards higher-value food items like rice and prepared cereal products. There is also a noticeable increase in the consumption of fruits and animal-source products as income level increases, while there is no significant change in the consumption of vegetables.

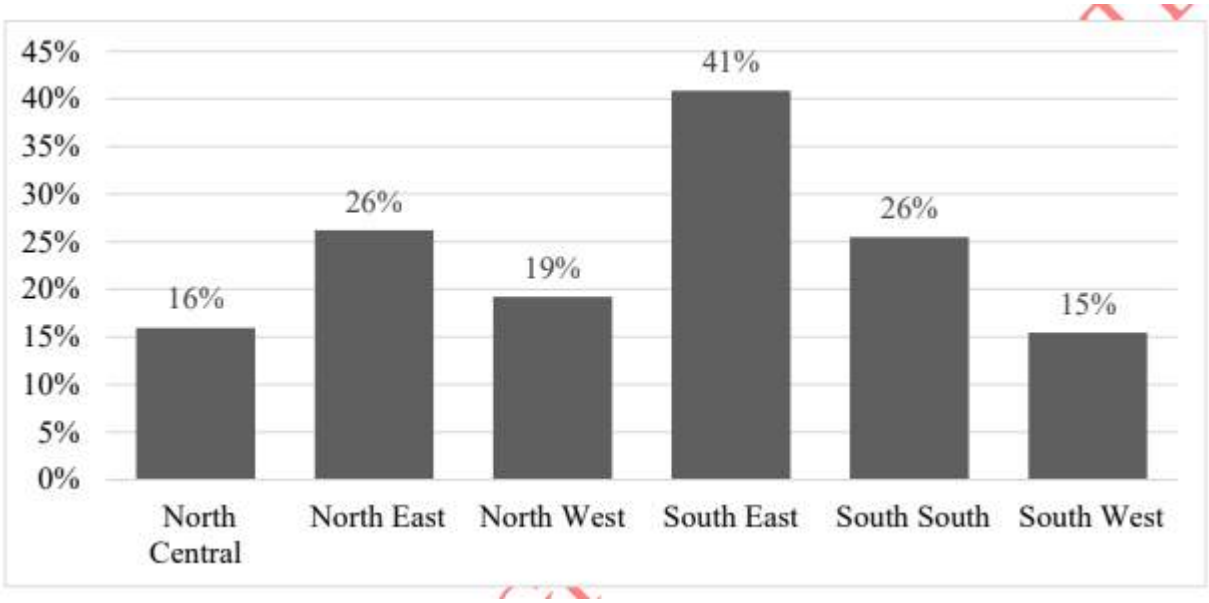
Figure 6: Consumption of different food groups, by income group



Source: Authors' computation

Figure 7 shows the estimated food gap by geo-political zone. The criteria for measuring food gap is food consumption equivalent to less than 2,100 kcal/AE/day. On average, 22% of Nigerian households are estimated to experience a food gap. The results also show a significant regional variation. For this data survey period, while the South West and North Central regions have the lowest food gap at 15% and 16% respectively, the South East region has the highest food gap at 41%. There is a need for further investigation to ascertain the situation of food security in the South East during the survey period.

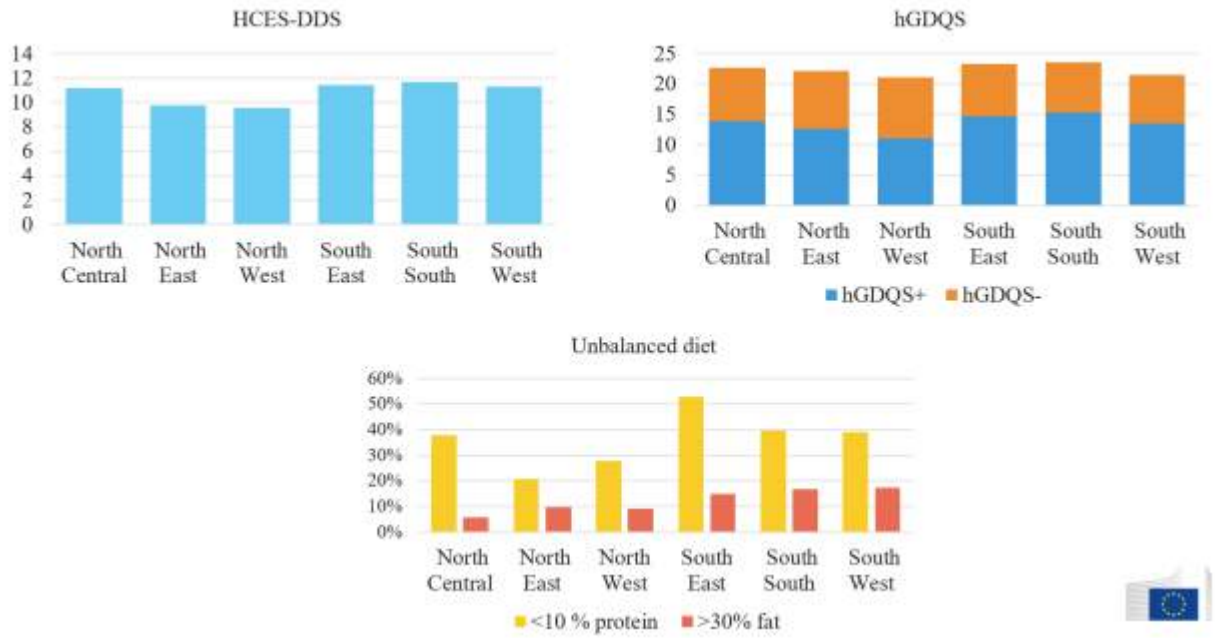
Figure 7: Estimated food gap, by geo-political zones



Source: Authors' computation

Figure 8 shows indicators of diet quality. On average, the HCES-DDS (diet diversity) score of 11 out of 16 shows fair level of diet diversity. However, the hGDQS score of 22 out of 45 shows that the average diet quality is low. Meanwhile, about 85% of households consume less than 400 grams of fruits and vegetables daily (in line with WHO and FAO recommendations). Less than 44% of households consumes a balanced diet, 37% obtain less than 10% of their energy intake from protein while 13% obtain more than 30% of their energy intake from fats and oils. At the regional levels, Figure 8 shows that southern households have the highest HCES-DDS and hGDQS scores relative to northern households. This indicates that the latter households consume less diverse and less quality diets, particularly due to the lower intake of healthy food groups. In terms of unbalanced diet, the South perform worse than the North, due to the intake of fat and protein outside the recommended thresholds of the WHO. Compared to northern households, larger share of households in the South obtains less than 10% of their energy intake from protein and more than 30% from fats.

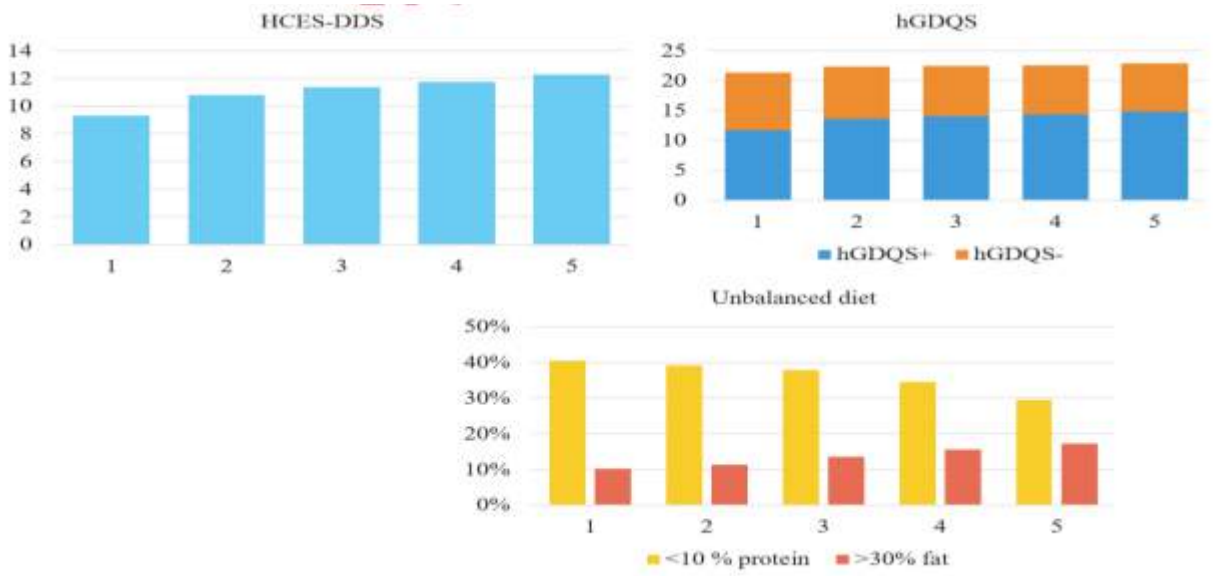
Figure 8: Diet quality and diversity, by geo-political zone



Source: Authors' computation

As shown in Figure 9, the diet quality and diversity tend to increase as the income level increase. This is a reasonable conclusion as higher income enables households to improve the diversity and quality of their diet. However, income level is found to be inversely related to a balanced diet. As the income level increases, more households consume more fat and less proteins as recommended by WHO.

Figure 9: Diet quality and diversity, by income group



Source: Authors' compilation

5.2 Impacts of government policies to enhance food and nutrition security in Nigeria

This section presents the results of the CGE model which analyses the economy-wide impacts of public policies to enhance food and nutrition security. As noted earlier, this version of the paper only presents the results of two

scenarios – scenario 1 (increasing the productivity of key crops through improved access to inputs (fertiliser) and scenario 3 (improving household access to fertiliser to enhance production for own consumption). The macro-level results show that both policy scenarios lead to a decline in the consumer price index (CPI), with scenario 1 having a larger proportional decline in CPI (Figure 10). The decline in CPI is driven by the lower production costs associated with the improved efficiency of inputs induced by the fertiliser subsidy. The disproportionate effect in scenario 1 is largely due to the large scope of the efficiency improvement compared to scenario 3 where this is limited to household production for own consumption. Due to the policy interventions, total investment expenditure increases as the lower production costs stimulate investment in key economic sectors. As a result, real GDP increases in both scenarios (by 0.32% and 0.283% under scenarios 1 and 3 respectively). The policy intervention implemented at a larger scale (scenario 1) has a larger effect on real GDP than scenario 3, which is limited to household production.

Figure 10: Macro-impacts of policy scenarios, (changes from the baseline, %)

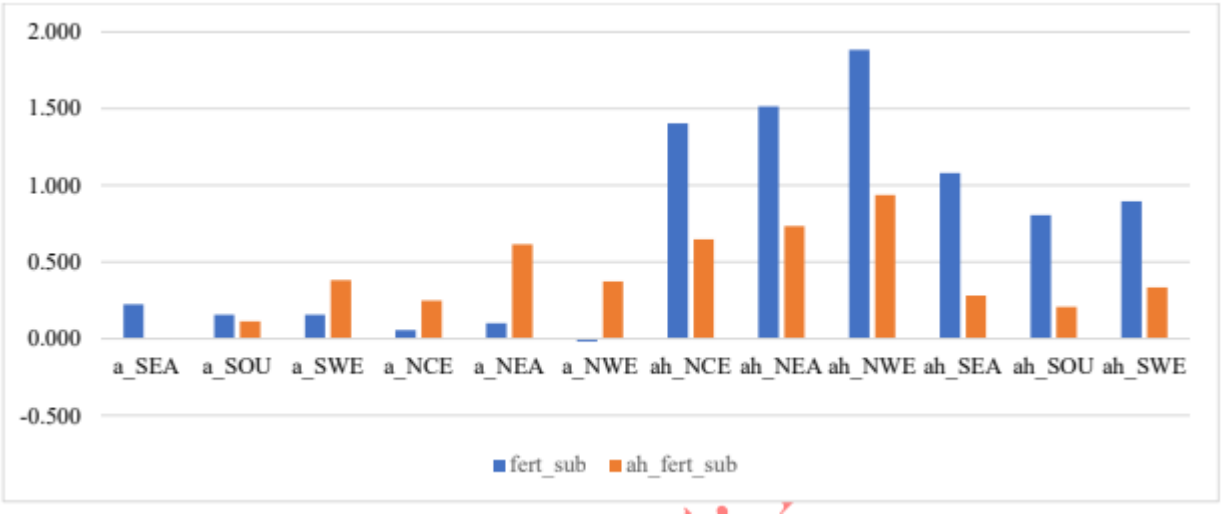


Source: Authors' computation

Figure 11 also presents the domestic production by regional agriculture sector. At the regional level, agriculture output increases for all regions except the North West for scenario 1. The regional effects on agriculture output vary based on the scenario. Under scenario 1, the agriculture output of the South East, South South, South West, North East, North Central increase by 0.224%, 0.156%, 0.156%, 0.101% and 0.057% respectively. However, the output of North West declines by 0.017%. Under scenario 3, the output of North East, South West, North West, North Central, South South and South East increase 0.615%, 0.382%, 0.374%, 0.248%, 0.114% and 0.001% respectively. For household agricultural production output, scenario 1 has a proportional larger impact than scenario 3. Under scenario 1, the North West (1.883%), North East (1.516%) and North Central (1.404%) have the largest impact on household production output.

Figure 11: Impacts on regional agriculture activities, (changes from the baseline, %)

Source:

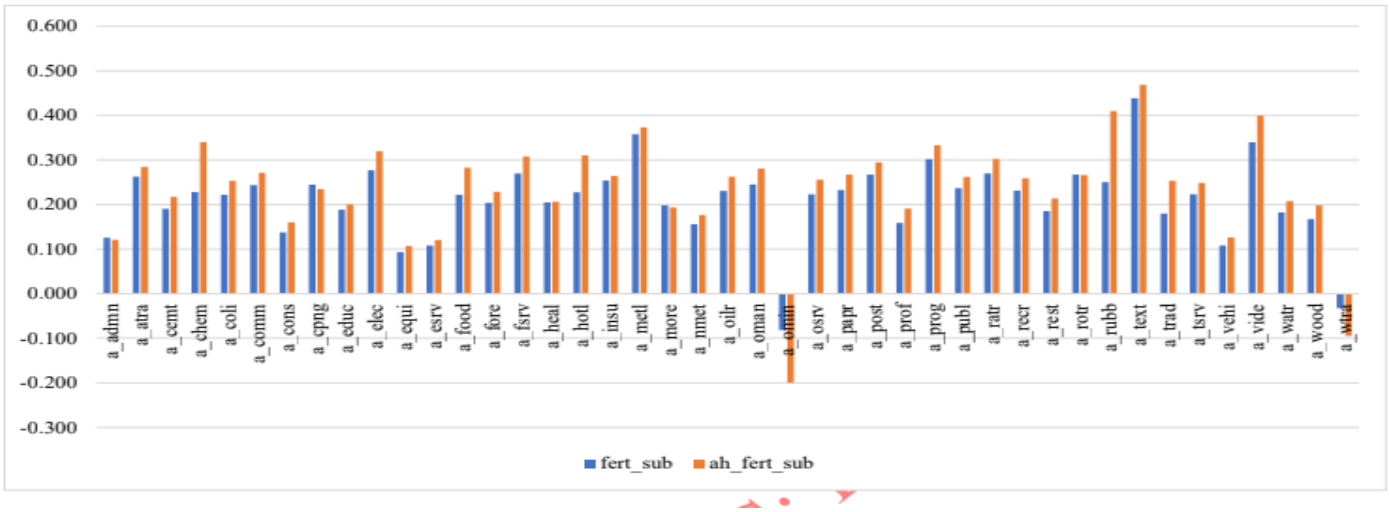


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The policy interventions will have effects beyond the agriculture sector (Figure 12) via linkages with other sectors as well as the re-allocation of production resources. Overall, there is a positive effect on all non-agriculture sector except quarrying and other minerals sector and water transport sector, but an obvious fact from the results is that scenario 3 has a relatively larger effects on non

agricultural output than scenario 1. Among the non-agriculture sector, the largest impact is felt in the textile sector, with output increasing by 0.439% under scenario 1 and 0.469% under scenario 3. The motion pictures/sound recording and music production sector will also have output increase by 0.340% and 0.400% under scenarios 1 and 3 respectively. Similarly, the output of the basic metals, iron and steel sector will increase by 0.358% and 0.373% in both scenarios respectively. On the negative side, the output of the quarrying and other minerals sector will decline by 0.082% and 0.200% in both scenarios respectively and that of the water transport sector will decline by 0.032% and 0.095%.

Figure 12: Impacts on outputs of non-agriculture sector (changes from the baseline, %)

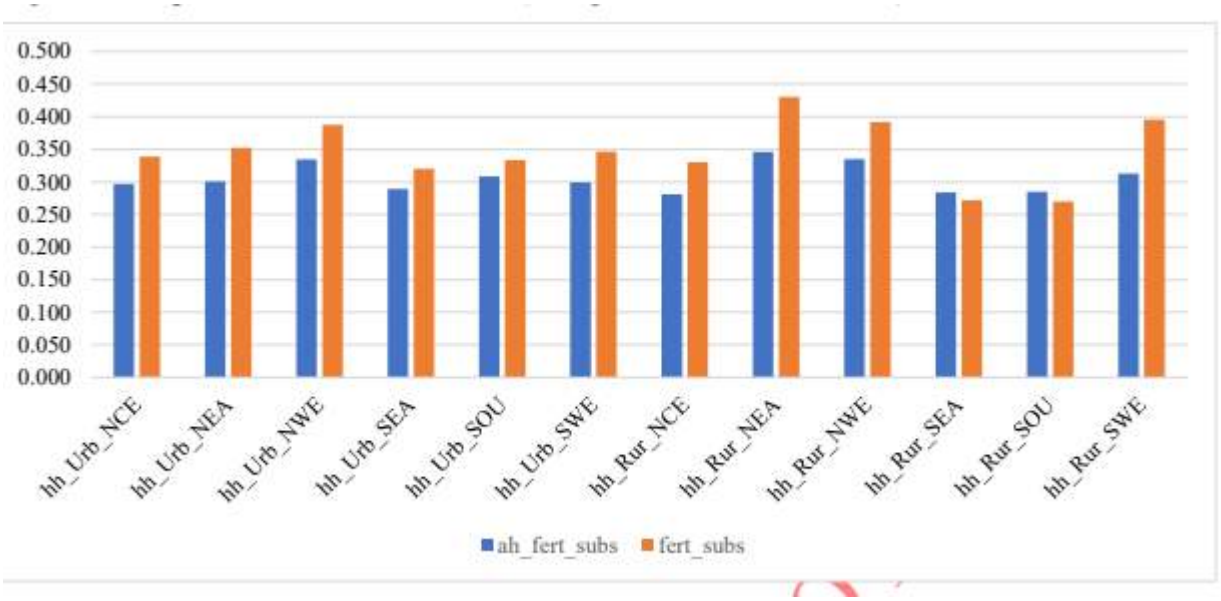


Source: Authors' computation

The impact of the policy interventions on household income is presented in Figure 13. The implementation of the

fertiliser subsidy increases the demand for production factors to stimulate increase in production. The increased demand for production factors results in increase in the price of the factors, contributing to an increase in household income. The results shows that the fertiliser subsidy for the overall economy has a much larger effect than the fertiliser subsidy targeted at home production for own consumption. The subsidy can stimulate a much higher demand in production factors, thereby having a disproportionate higher effect on production factors. Household income increases highest for rural North East households (0.431% and 0.345%), followed by rural South West households (0.396% and 0.313%) and then North West households (0.392% and 0.335%). These three household groups also have the highest increase in household income in urban areas. The household groups that experience the lowest income growth are rural South East (0.272% and 0.284%) and rural South South households (0.270% and 0.285%).

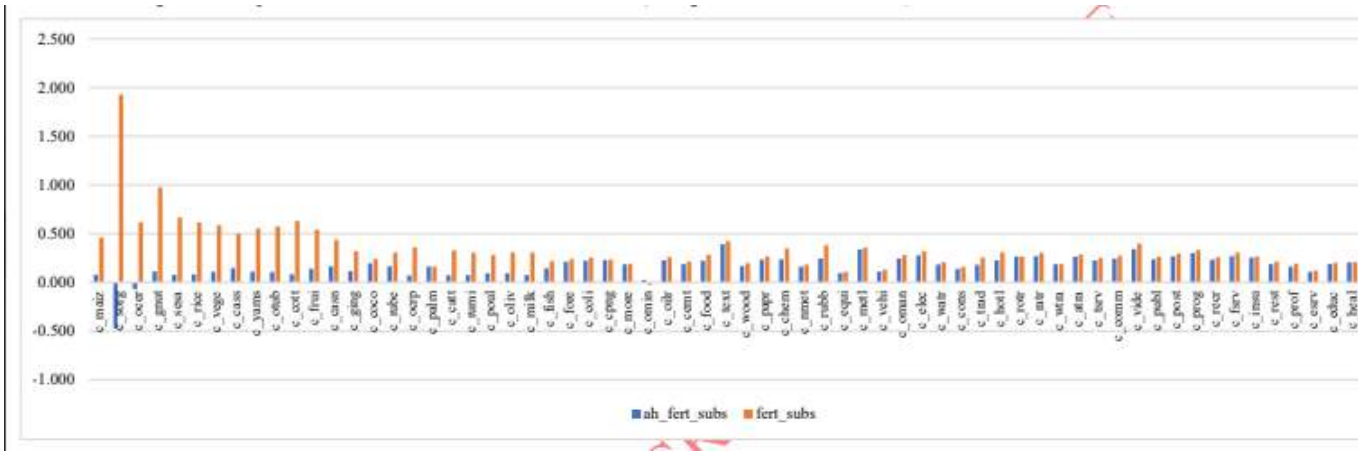
Figure 13: Impact on household income, (changes from the baseline, %)



Source: Authors' computation

The increase in household income leads to increase in domestic demand for commodities. As shown in Figure 13, the domestic demand for all commodities increase in both scenarios except for sorghum, other cereal and quarrying and other minerals. Domestic demand for sorghum increase by 1.927% under 1 scenario but decline by 0.474% under scenario 3. The increase in domestic demand is higher under scenario 1 compared to the scenario 3. This may be due to the scale of the impact of the overall fertiliser subsidy compared to the subsidy targeted at household farmers. Figure 14 shows the impact on food production. Overall, food consumption increases for all household categories, with rural North East (0.409%), South West (0.386%) and North West (0.387%) recording the largest increase in food consumption.

Figure 13: Impact on domestic demand for commodities, (changes from the baseline, %)



Source: Authors' computation

6. Conclusion

This is a work-in-progress paper to examine the impact of e results of this paper show the relative effectiveness and impacts of policies to improve food and nutrition security in Nigeria. The paper analyses survey data to understand the food consumption pattern of Nigerian households, across regions and income level as well as the diet quality and diversity. A macroeconomic model is also employed to analyse the impact of specific policies. The DEMETRA CGE model is linked to Nigeria's SAM to analyse the macroeconomic and distributional impact of the policies. The paper is still ongoing as several scenarios are yet to be taken into consideration, and the CGE results will be further linked to a micro-model that links changes in food consumption to diet and nutrition indicators.

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Appendix: Overview of food and nutrition security policies in Nigeria

Source: Authors' compilation

Name of programme	**Start year**	**Areas of intervention**	**Key actors**	**Funding sources**	**Evidence of impact**	**Challenges**
National Food Security Programme (NFSP)	2008	Broadening local production of food, minimizing food importation, enhancing agricultural output, increasing farmer's income	Federal Ministry of Agriculture and Water Resources	-	-	Weak infrastructure, limited extension services, constrained access to contemporary farming inputs and technologies
Agricultural Transformation Agenda (ATA)	2011	Strengthening the nation's agricultural sector, expanding agricultural output, boosting food sufficiency, generating employment opportunities	Federal Ministry of Agriculture and Rural Development	-	-	Inadequate credit access for farmers and agribusinesses, weak rural infrastructure, increasing insecurity in the country
Anchor Borrowers'	2015	Expanding credit and farm finance, offering agricultural	Central Bank of Nigeria	-	-	Farmer's inability to pay back the loans,

Programme (ABP)		inputs in cash and kind support for small-scale farmers				funds mismanagement, corruption, issues of funds diversification
Agricultural Sector Food Security and Nutrition Strategy (2016-2025)	2016	Improving food security at the household and national levels, increasing access to safe and nutritious food, reducing malnutrition	Federal Ministry of Agriculture and Rural Development	Government budgets, donor agencies, private-sector partnerships	Some progress in crop production and biofortification	Poor infrastructure, limited fiscal space, inefficient coordination, effects of climate change
National Policy on Food and Nutrition in Nigeria (2016 update)	2016	Reducing hunger and malnutrition, improving nutritional knowledge, promoting food safety, enhancing household food security	Federal Ministry of Budget and National Planning	Government allocations, international aid	Some progress in school feeding programs and food fortification	Limited funding, weak infrastructure, poor coordination among sectors, scarcity of qualified nutritionists, cultural barriers
National Social Investment Programme (NSIP)	2016	Addressing poverty and hunger through diverse social assistance projects	Federal Ministry of Humanitarian Affairs,Disaster Management and Social Development	-	-	Insufficient funding, mismanagement
Home-Grown School Feeding Programme (HGSFP)	-	Expanding primary school enlistment and attendance, increasing children's nutritional outcomes	Federal Ministry of Humanitarian Affairs, Disaster Management and Social Development	-		Insufficient funding, mismanagement, poor nutritional quality and quantity of meals
National Strategic Plan of Action for Nutrition (NSPAN) 2021-2025	2021	Improving nutrition through healthcare services, particularly focusing on maternal and child nutrition and preventing nutrition-related non communicable diseases	Federal Ministry of Health	Government resources, international donors	-	Widespread food insecurity, weak rural health infrastructure, insufficient health funding, poor coordination among stakeholders
National Multi-Sectoral Plan of Action for Food and Nutrition (NMPFAN) 2021- 2025	2021	Improving the nutritional status of all Nigerians, particularly vulnerable groups, through multi-sectoral interventions	Federal Ministry of Finance, Budget and National Planning	Government budget, development assistance, donations, other sources	Progress in improving breastfeeding rates and integration of nutrition into primary health care	Limited funding, coordination, infrastructure, and cultural challenges, regional disparities in food access, insecurity
National Social Investment Programme (NSIP)	2016	Addressing poverty and hunger through diverse social assistance projects	Federal Ministry of Humanitarian Affairs,Disaster Management and Social Development	-	-	Insufficient funding, mismanagement

Home-Grown School Feeding Programme (HGSFP)	-	Expanding primary school enlistment and attendance, increasing children's nutritional outcomes	Federal Ministry of Humanitarian Affairs, Disaster Management and Social Development	-		Insufficient funding, mismanagement, poor nutritional quality and quantity of meals
National Strategic Plan of Action for Nutrition (NSPAN) 2021-2025	2021	Improving nutrition through healthcare services, particularly focusing on maternal and child nutrition and preventing nutrition-related non communicable diseases	Federal Ministry of Health	Government resources, international donors	-	Widespread food insecurity, weak rural health infrastructure, insufficient health funding, poor coordination among stakeholders
National Multi-Sectoral Plan of Action for Food and Nutrition (NMPFAN) 2021- 2025	2021	Improving the nutritional status of all Nigerians, particularly vulnerable groups, through multi-sectoral interventions	Federal Ministry of Finance, Budget and National Planning	Government budget, development assistance, donations, other sources	Progress in improving breastfeeding rates and integration of nutrition into primary health care	Limited funding, coordination, infrastructure, and cultural challenges, regional disparities in food access, insecurity

Source: Authors' compilation

PAPER NAMM-1101225

Electricity Access, Usage Patterns, and Alternative Energy Solutions in Halls of Residence: A Case Study of Abdulsalami Abubakar Postgraduate Hall at the University of Ibadan, Nigeria

Makuachukwu U. Moneke and Olusanya E. Olubusoye

Abstract

Reliable electricity is essential for academic productivity and student welfare, yet supply to Nigerian university halls of residence remains erratic. This study examines electricity access, usage patterns and coping strategies in Abdulsalami Abubakar Postgraduate Hall, University of Ibadan. Using a mixed-methods case study design guided by behavioural economics, it combines a structured survey of hall residents with semi-structured interviews of three key informants responsible for electricity provision and hall management; survey data were analysed with descriptive statistics and interview data with thematic analysis. Nearly all responses (97.8%) describe supply as available but interrupted. Typical outages last four to eight hours (51.9%) or eight to twelve hours (33.2%), and more than half of outages (53.4%) occur in the evening, the period in which 52.4% of responses place peak demand. Electricity is used mainly for charging devices, laptop-based study and lighting. Residents cope largely through power banks (47.3%) and rechargeable or solar lamps and fans (24.7%), while about a quarter use no alternative at all. Outages chiefly disrupt device charging (40.8%) and studying (34.4%), and make rooms unsafe or uncomfortable (23.9%). Interviews trace unreliability to ageing internal infrastructure and limited room-level backup, and reveal conditional support for solar and hybrid systems. The study recommends infrastructure renewal, a hall-level solar-plus-storage system with clear maintenance arrangements, and demand-side measures to encourage responsible use.

Keywords: Electricity Access, Usage Patterns, Alternative Energy Solutions, Student Halls of Residence, Sustainable Development.

1. Introduction

Electricity underpins almost every aspect of university life, from lighting and laptops to internet access, water supply and the habitability of residential spaces (Diyoke et al., 2023). In sub-Saharan Africa, unreliable supply remains a major obstacle to Sustainable Development Goal 7 and limits students' ability to study after dark and to use modern learning technologies (Opedare et al., 2020; Elom et al., 2024; Sharif & Khan, 2023). Nigeria illustrates the problem sharply: a persistent gap between demand and supply, rooted in weak generation, transmission and distribution infrastructure, leaves public universities dependent on costly and polluting diesel generators (Diyoke et al., 2023; Kuhe et al., 2025; Omeiza et al., 2022).

At the University of Ibadan, lecture halls, libraries and administrative buildings often receive priority supply or generator backup, while student halls of residence are left without power for long periods. For postgraduate residents this means difficulty charging devices, studying at night and keeping rooms cool, with consequences for productivity, welfare and safety (Bello & Ezeokoli, 2020; Mbazor, 2021; Malik et al., 2022; Musa et al., 2021; Thembane, 2024). Initiatives such as the Energizing Education Programme have brought solar power to some campuses, but mainly to central facilities rather than residences (Saturday, 2021), and there is little structured evidence on how electricity is actually used in halls, how students cope with outages, or which alternatives would close the gap (Oyedepo et al., 2016).

This study addresses that gap for Abdulsalami Abubakar Postgraduate Hall. It has three objectives: (i) to assess the duration and reliability of electricity supply in the hall; (ii) to identify residents' patterns of electricity use, including the main purposes of use and the periods of peak demand; and (iii) to examine the alternative power sources residents rely on during outages and how outages affect them. The findings inform the case for decentralised hybrid energy solutions in university housing, building on earlier techno-economic work on the same hall (Opedare et al., 2020).

2. Literature Review

Electricity access is now understood as multidimensional: beyond a grid connection, it concerns the capacity, duration, reliability, affordability, safety and quality of supply, as captured in the World Bank's Multi-Tier Framework (Nwaobia et al., 2023). Reliability, measured by the frequency and length of interruptions, largely determines the benefit users derive from a connection, while affordability determines whether available power can be used (Sharif & Khan, 2023). In halls of residence, demand is shaped by occupancy, appliance ownership, time of day and behaviour. Because residents rarely pay for electricity directly, price signals are weak, and habits, social norms and information gaps matter more. Behavioural economics, with its attention to bounded rationality, social norms and nudges, therefore offers a useful lens, alongside energy-poverty perspectives that link unreliable supply to reduced educational capabilities (Sharif & Khan, 2023; Malik et al., 2022).

Empirical work on Nigerian universities has concentrated on the techno-economic feasibility of solar and hybrid systems, showing that solar photovoltaic generation with battery storage can reduce reliance on the grid and on diesel generators (Opedare et al., 2020; Ajiboye et al., 2022; Gbadamosi et al., 2022; Kuhe et al., 2025), while adoption is held back by high initial costs and limited technical capacity (Abdullahi et al., 2022). Studies elsewhere document the academic and welfare costs of load shedding for students (Malik et al., 2022; Thembane, 2024) and the wider economic cost of unreliable grid power in Nigeria (Olówósejéjé et al., 2019). What is missing is evidence that links supply conditions, actual usage patterns and coping strategies within a single residential hall, which is the gap this study fills.

Figure 1 summarises the conceptual framework. Electricity access, defined by the availability, reliability and duration of supply, shapes how residents use electricity; frequent interruptions push them towards alternative sources; and together these determine welfare outcomes such as comfort, security and academic productivity. Residents' behavioural responses feed back into both demand and the use of alternatives.

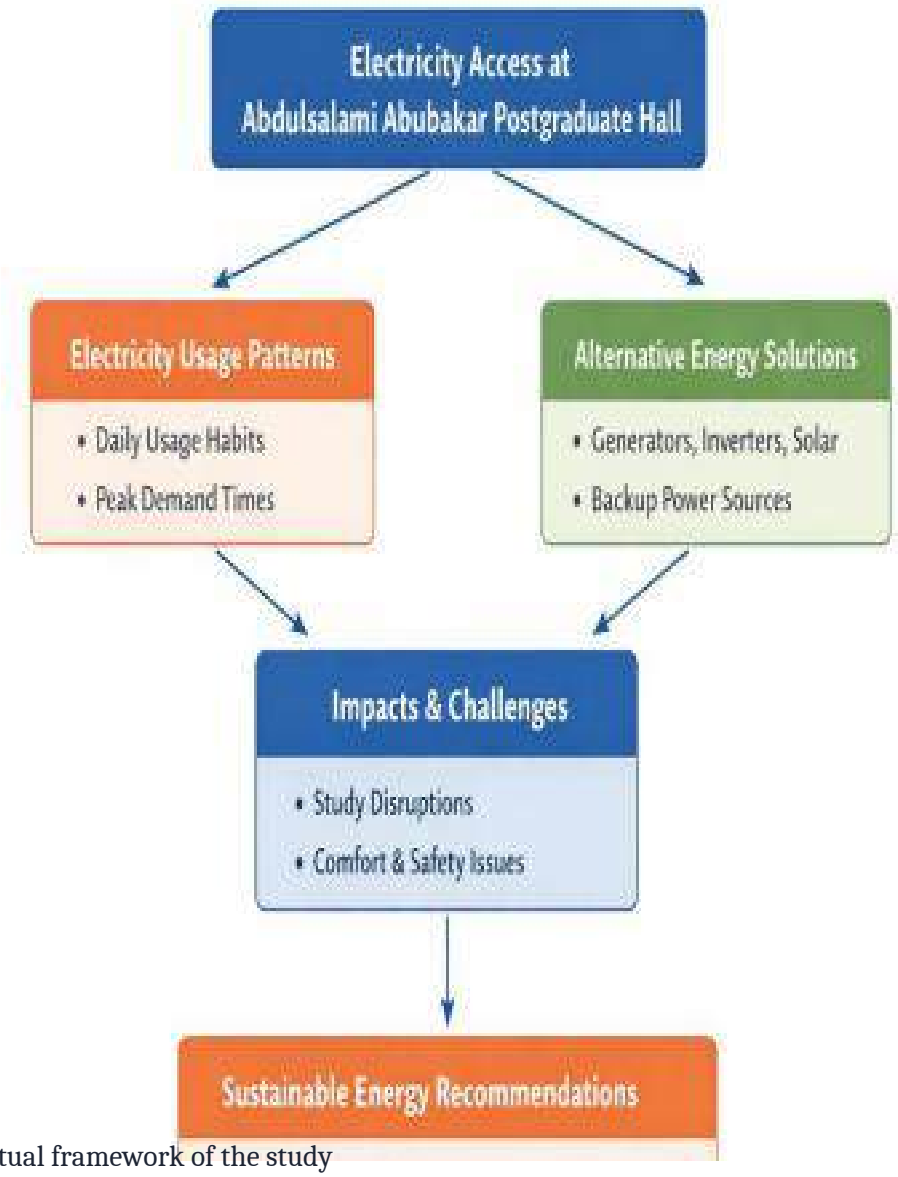


Figure 1: Conceptual framework of the study
*(**Source:** Author's Design)*

3. Methodology

The study adopts a mixed-methods case study design guided by behavioural economics, which recognises that electricity use in shared residences is shaped by habits, social norms and convenience rather than by price signals alone: residents of the hall are not individually metered or billed. Abdulsalami Abubakar Postgraduate Hall houses full-time and part-time postgraduate students from across the University of Ibadan. It draws power from the Ibadan Electricity Distribution Company (IBEDC) through the university's central network, and its limited backup generation serves mainly water pumping and administration rather than residents' rooms.

Quantitative data were collected with a structured questionnaire, administered in person to randomly selected residents, covering electricity availability; the frequency, duration and timing of outages; uses of electricity; alternative power sources; and the perceived effects of outages. The survey yielded 1,952

responses on supply conditions. Qualitative data came from semi-structured interviews with three purposively selected key informants (a senior engineer, a hall supervisor and a hall porter), supplemented by site visits to observe the hall's electrical infrastructure. Survey data were analysed with descriptive statistics and interview transcripts with thematic analysis, and the two strands were triangulated. Participation was voluntary and confidential, and institutional permission was obtained.

4. Results

Results are reported as percentages of survey responses. Respondents were 54.9% female and 45.1% male.

4.1 Access and reliability of supply

Supply in the hall is best described as available but unreliable. Almost all responses (97.8%) report that electricity is available with interruptions; only 1.6% report uninterrupted supply all day and 0.6% no supply at all (Figure 2). Interruptions are long: just over half of outages last four to eight hours (51.9%), a third last eight to twelve hours (33.2%) and one in ten (9.9%) last twelve hours or more (Figure 3).

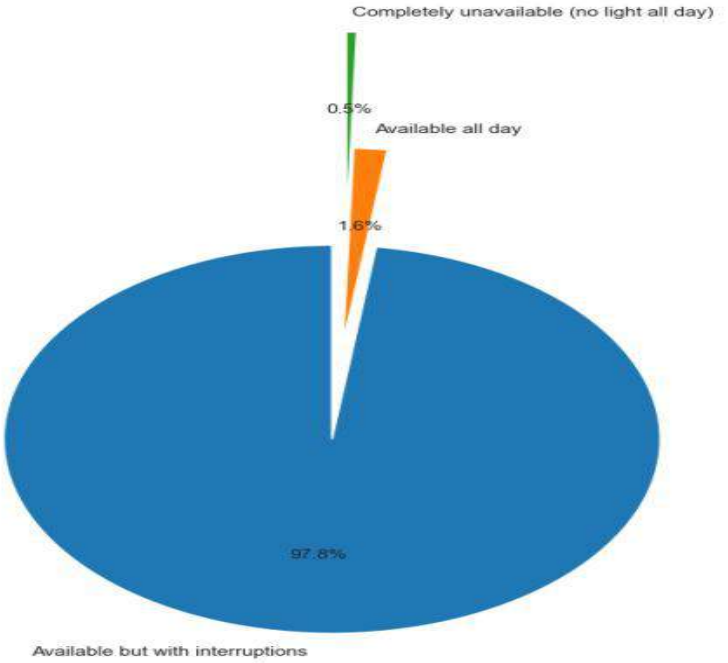


Figure 2: Electricity availability in the hall

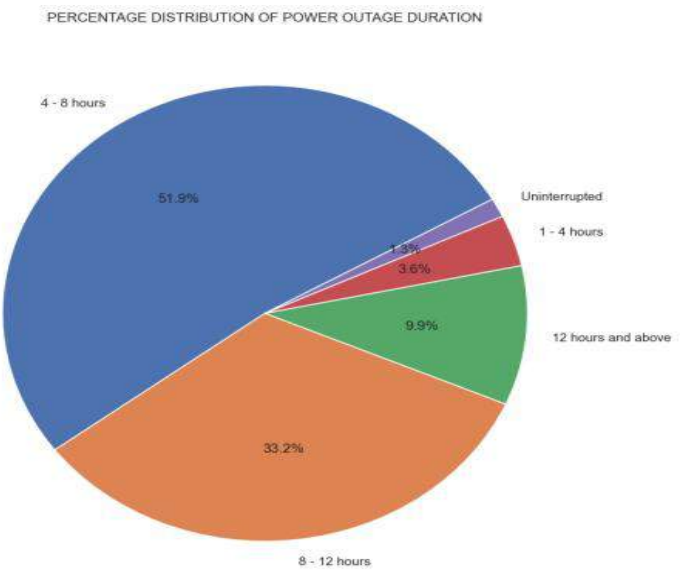


Figure 3: Duration of a typical power outage

Over a whole day, supply is nonetheless substantial for most residents: 44.7% of responses report 12 to 16 hours of electricity a day and 36.1% more than 16 hours, while 18.0% report 12 hours or fewer (Figure 4). The problem is therefore less the total number of hours than when the outages fall. More than half of outages (53.4%) occur in the evening, between 6 pm and midnight (Figure 5), whereas power is most often available at night, between midnight and 6 am (44.3%).

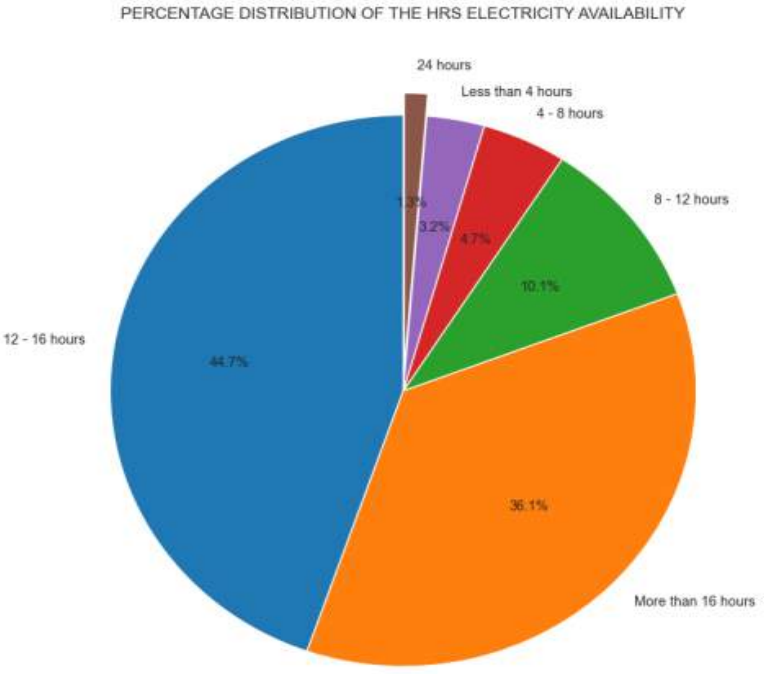
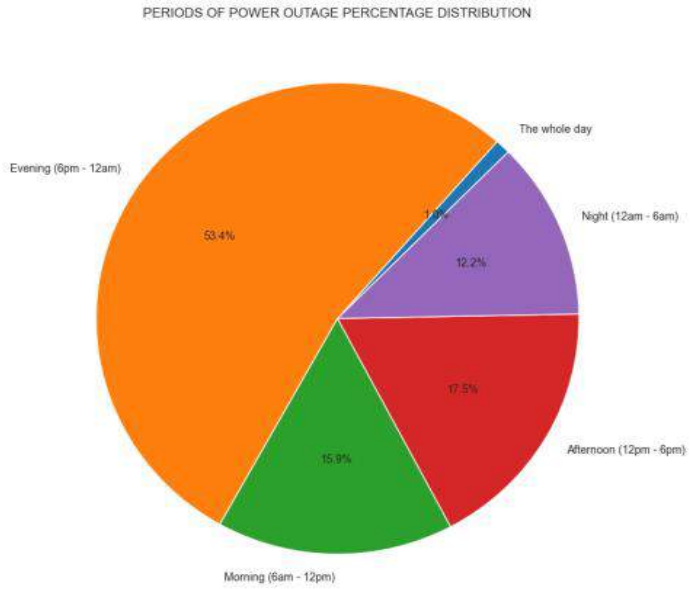


Figure 4: Daily hours of electricity supply

Figure 5: Time of day when outages occur



4.2 Patterns of use and peak demand

Demand is concentrated at exactly the time supply is weakest. The evening accounts for 52.4% of responses on peak demand, followed by the afternoon (17.7%), night (17.1%) and morning (12.7%) (Figure 6). Use is overwhelmingly necessity-driven: charging phones and other devices (31.5%), laptop-based study (24.1%) and lighting (21.2%) together account for more than three-quarters of reported uses, with fans (9.5%), ironing (6.0%), entertainment (5.2%) and cooking appliances (2.2%) making up most of the rest (Figure 7).

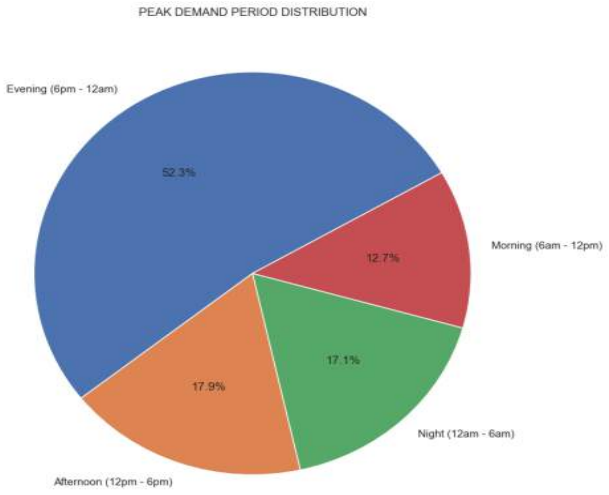


Figure 6: Periods of peak electricity demand

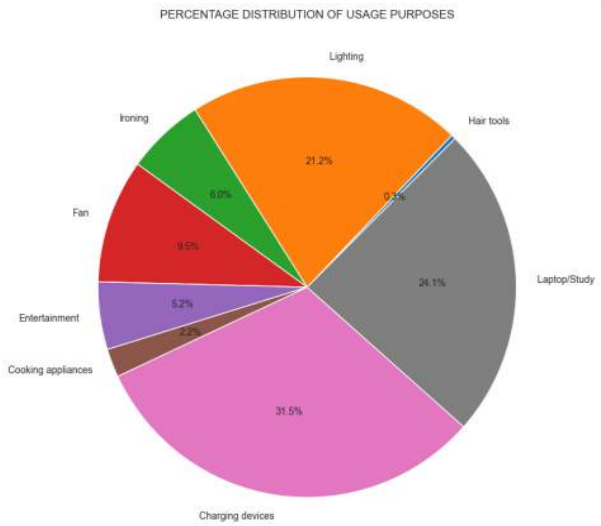


Figure 7: Main uses of electricity

4.3 Coping strategies and effects of outages

Residents cope mainly with small personal devices. Power banks are the most common alternative (47.3%), followed by rechargeable lamps or fans (17.6%) and solar lamps or fans (7.1%); hall generators (0.7%) and candles (0.6%) are rarely used, and 26.8% of responses report using no alternative at all (Figure 8). Reliance on these sources is usually short: 35.2% of responses report two to four hours a day and 31.8% less than two hours, while 19.0% depend on them for more than four hours.

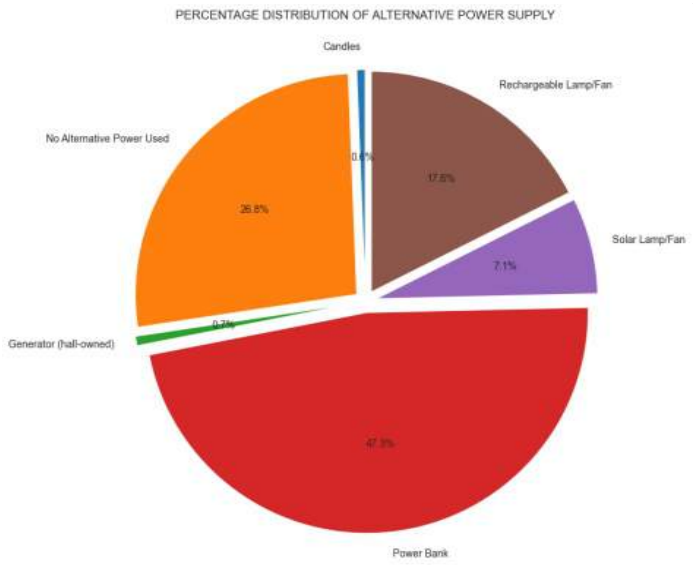


Figure 8: Alternative power sources used during outages

Outages affect residents most through device charging (40.8%) and disrupted studying and assignments (34.4%); 23.9% say outages make their rooms unsafe or uncomfortable, and fewer than 1% report no major impact (Figure 9).

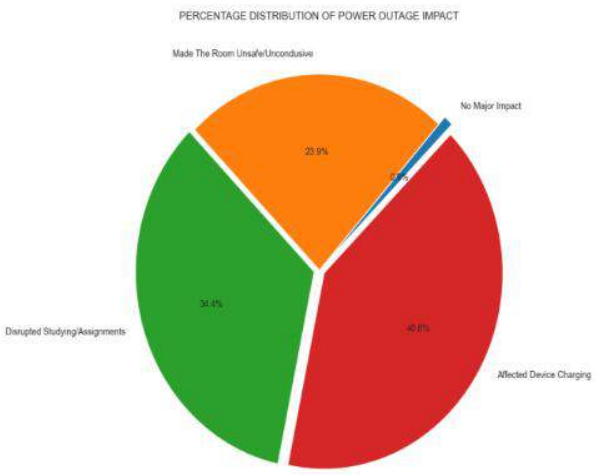


Figure 9: Main effect of power outages on residents

5. Discussion

The interviews help explain these patterns. Informants attributed unreliable supply less to the grid than to conditions inside the university: ageing cables, poor internal wiring and recurrent transformer faults. Access in the hall is therefore nominal rather than functional. The hall is connected, but the connection does not deliver dependable service, a pattern consistent with the multidimensional view of access (Nwaobia et al., 2023).

The mismatch between the timing of outages and the timing of demand is the study's central finding. Supply is most dependable after midnight, while evening outages coincide with the hours residents need for study, research and charging. Informants also reported lights and appliances being left on unnecessarily, which suggests that demand-side measures, and not only investment in supply, can relieve pressure on scarce evening power.

Coping strategies shift the cost of unreliable supply onto residents. Institutional backup serves water pumping and administration rather than rooms, so students buy power banks, rechargeable lamps and solar devices themselves. These purchases bring short-term relief but add financial burdens, and a quarter of responses report no alternative at all. In a postgraduate hall, where research and digital work are central, the resulting disruption to charging and studying is consistent with energy-poverty arguments linking poor energy services to weaker educational outcomes (Sharif & Khan, 2023; Thembane, 2024).

Informants were optimistic about solar and hybrid systems, particularly for lighting and basic services, but stressed maintenance, misuse and governance in a communal setting. Table 1 summarises the main themes from the interviews.

Table 1: Themes from the key informant interviews

Theme	Codes Identified	Illustrative Focus
Structural and Technical Constraints	Ageing infrastructure, faulty transformers, weak cables, and wiring failures	Internal causes of unreliable electricity supply
Grid Dependence and Limited Backup	IBEDC reliance, generator use for water, and lack of room-level backup	Institutional energy vulnerability

Temporal Supply Patterns	Night-time availability, daytime outages, irregular supply	Time-based electricity inequality
Welfare and Security Impacts	Disrupted studying, device charging issues, and security risks	Electricity as a welfare service
Solar Energy Acceptance	Support for solar, mini-grid ideas, and maintenance concerns	Conditional openness to renewables
Student Behaviour and Energy Use	Appliance misuse, lights left on, and a lack of conservation	Demand-side challenges

6. Conclusion and Recommendations

Electricity access in Abdulsalami Abubakar Postgraduate Hall is inadequate for residents' academic and welfare needs, not because the hall lacks a connection but because supply is interrupted for long periods at the times it is most needed. Residents' use of electricity is modest and largely academic, which counters the assumption that high demand reflects luxury consumption, and the burden of coping falls on the residents themselves.

Four measures follow. First, the university should prioritise renewal of the hall's internal infrastructure, including ageing cables, wiring and transformers, with routine inspection. Second, a decentralised hall-level hybrid system combining the university supply with solar panels and battery storage should be deployed to secure evening supply, building on existing feasibility work (Opedare et al., 2020; Gbadamosi et al., 2022). Third, any such system needs clear governance: designated maintenance staff, funding arrangements and usage rules. Fourth, low-cost demand-side measures such as signage, orientation sessions and behavioural nudges should encourage responsible use. More broadly, electricity supply should be treated as part of student welfare policy.

The study is limited to a single hall and did not examine variation between residential blocks. Future work could compare several halls or universities, carry out a full cost-benefit analysis of hybrid systems, and test prepaid metering and smart energy management in student residences.

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Modelling Digital Finance and Macroeconomic Performance in Nigeria

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Abstract

This paper examines the dynamic relationship between digital finance and macroeconomic performance in Nigeria, based on the Financial Innovation Theory and the Supply-Leading Hypothesis, using quarterly data from 2012Q1 to 2024Q4. While previous research has primarily examined the one-way impact of digital finance on growth, this paper fills a unique gap by modelling the dynamic interactions between digital finance, real GDP, inflation, household consumption, and monetary policy using a Structural Vector Autoregression (SVAR) model that captures structural shocks and addresses endogeneity. The SVAR results indicate that digital finance shocks lead to short-term fluctuations in inflation, consumption, and monetary policy, but their impact on real GDP is gradual and minor. The variance decomposition indicates that digital banking is primarily driven by its own innovations, with inflation and output contributing more to long-term changes. The GMM findings also show that real GDP and inflation have a significant impact on digital finance, whereas monetary policy and consumption have weaker effects. Overall, the analysis highlights the significant relationship between digital finance and macroeconomic fundamentals, underscoring the importance of stable macroeconomic conditions for the continued deepening of digital finance in Nigeria.

Keywords: Digital finance, SVAR, Macroeconomy, Shocks, Nigeria.

JEL Classifications: E2, E44, G2

1. Introduction

The global financial system is rapidly evolving, with digital finance emerging as the central pillar for promoting financial inclusion and reducing transaction costs. According to the Global Findex Database (2021), the proportion of account holders increased from 51 percent in 2011 to 76 percent in 2021, and 71 percent in developing countries. Globally, the financial sector is shifting its focus to providing digital services through the use of technological enablers.

According to Nkechika (2022), the goal is to meet public demands, assist governments with current challenges, and identify potential future innovations in a competitive market. This rapid technological development has spurred an increase in various digital payment channels, commonly referred to as digital finance. The provision of financial services through digital platforms promotes financial inclusion, especially in developing countries.

As stated by Gąsiorkiewicz and Monkiewicz (2022), Digital finance encompasses the digital components of the financial system, such as the internet, payment cards, ATM use, cryptocurrency assets, and the overall financial infrastructure. Additionally, it encompasses all mobile services and electronic applications. The use of these technologies aids speed, comfort, and ease of access in the delivery of financial services. Consequently, it promotes business expansion and reduces complexity.

Digital finance in Nigeria has evolved from mere innovation to a critical element of its financial system, particularly with the launch of the Central Bank of Nigeria's Payment System Vision 2020 (PSV2020)

and the 2012 cashless policy, which aimed to reduce the volume of cash circulating in the economy. The digital economy is one of the most active fields in Nigeria's development. The sector, which comprises the Information and Communication (I&C) sector and the Financial Institutions (FI) sector, is one of the top 10 growing sectors in Nigeria, contributing about 14.4 percent to the Real Gross Domestic Product (RGDP) in the second quarter of 2025 (National Bureau of Statistics, 2025). In Nigeria, the emergence of digital finance has gradually displaced cash with various digital payment channels, including mobile transactions, Point-of-Sale (POS) systems, internet banking, and Automated Teller Machines (ATMs). These digital platforms facilitate the interaction of multiple parties online, thereby encouraging financial inclusion in Nigeria to about 45 percent in 2021 (Global Findex Database, 2021). Financial institutions can now provide a broader range of customers with access to financial products and offer more services at lower rates.

It is expected that a stable and growing financial sector in any economy should have a positive and significant impact on the overall growth of the economy. Hence, digital finance increases aggregate demand and improves productive capacity. This can be achieved through the provision of credit, which enhances speedy payment, reduces transaction costs, and expands access to insurance, credit, and savings for families and businesses. Moreover, the relationship between this digital finance and the macroeconomy can be seen as two-way and dynamic, as supported by Ferreira (2021). The growth of the macroeconomy also propels growth in the financial sector, thereby leading to improvement in technology and access to finance.

Therefore, attention needs to be paid to it to understand how digital finance can be expanded into other sectors, thereby stimulating consumption patterns and employment levels in Nigeria. Many studies like; Suka and Samuel (2024), Aigbovo and Izekor (2024), Iwedi (2024), Onwere and Oke (2023) and Ramos and Olweny (2021), have empirically analyzed the impacts of digital finance on economic growth or economic development, while Ferreira (2021) carried out a panel granger causality between financial development and economic growth across many countries. In line with all of these, little attention has been placed on the two-way relationship between digital finance and the macroeconomy in Nigeria.

Hence, the main objective of this study is to fill the gap by examining the bidirectional relationship between the growth of digital finance and the aggregate economy in Nigeria. In addition to this, the study will utilize a dynamic model, such as the SVAR technique, which will link digital finance indicators with macroeconomic variables specific to Nigeria.

This paper is structured into five sections, with the introduction as Section 1, the literature review as Section 2, the methodology as Section 3, the discussion of results as Section 4, and the conclusion and recommendations as Section 5.

2. Literature Review

2.1 Conceptual Review

Digital Finance

Digital finance is often described as the delivery of financial services through various channels, including mobile phones, the internet, and payment cards. According to the World Bank (2022), digital finance refers to the delivery of financial services to previously unserved and underprivileged communities using digital technology such as mobile phones and the internet. The World Bank emphasizes the significance of digital finance in fostering financial inclusion, economic growth, and poverty alleviation, as it provides individuals and businesses with affordable, convenient, and secure access to financial services. Gąsiorkiewicz & Monkiewicz (2022) also defined digital finance as all-encompassing of all electronic applications and mobile services. Wang et al. (2020) also referred to digital finance as internet finance. He described it as a combination of both traditional financial services and digital technologies.

It is necessary to differentiate this term from other related concepts, such as financial inclusion and financial technology. Financial inclusion, on the one hand, refers to the accessibility of individuals to formal financial services or products at affordable costs with minimal effort (Suka & Samuel, 2024). Financial technology, on the other hand, according to Suryono et al. (2020), refers to connections between Internet-related technologies and commercial operations in the financial services sector. Financial deepening refers to the provision of a larger range of financial services made available to all (Echekoba & Ubesie, 2018). However, digital finance encompasses technology, deepening, and inclusion to create a dynamic system that directly affects overall economic growth, resilience, and development.

Digital Finance and Nigeria's Macroeconomic Performance

Prior to the evolution of digitalization, the Nigerian financial system was largely cash-based. This means that transactions were largely dominated by the use of cash. The digitalization of financial services has made access to these services easier, more convenient, and more cost effective. This can also be linked to the increased gains from production (Gal et al., 2019). The World Bank (2022) asserts that digital finance promotes financial inclusion and reduces poverty by making savings and credit accessible to people and businesses at affordable costs. At the aggregate level, digitalization of financial systems improves resource allocation, lowers transaction costs, and improves the efficiency of providing financial services. As a result of these improvements, investment levels, production, and consumption have increased. The advancement of digital finance significantly boosts economic resilience by enhancing innovation capabilities and consumer strength (Zou, Dai, & Meng, 2024). Hence, the stability of the financial sector of any economy significantly impacts the stability of the economy.

Nigeria, since 2007, has made efforts to switch to more electronic means of payment, especially with the launch of the Central Bank of Nigeria's Payment System Vision 2020 (PSV2020) and the 2012 cashless policy, which was aimed at reducing the volume of cash circulating in the economy, reducing cash transactions, and improving efficiency of the financial sector. In addition to this, the E-naira was launched in 2021, paving the way for digital currency adoption and improving efficiency and inclusion. Recently, a new strategic framework, the Payment System Vision 2028, has been launched. This is a drive towards a more inclusive and digital financial system in the country. According to the Nigeria Inter-bank Settlement System (NIBSS, 2025), the value of e-payment transactions increased to approximately N295 trillion in the first quarter of 2025, representing a year-on-year growth of around 17.7 percent. This reflects an increasing trend in digital payments, accompanied by a rise in point-of-sale transactions.

As the level of digital finance continues to rise, its growth is reflected in other sectors of the economy through various channels, including investment, consumption, and Gross Domestic Product (GDP) growth. However, as argued by Ferreira (2021), the relationship is bi directional. While digital finance spurs macroeconomic growth, the expansion of the economy equally accelerates the adoption of these financial technologies. The study by Al-Assaf et al. (2025) demonstrates how relevant macroeconomic variables influence digital finance. As GDP and incomes rise, so does the demand for improved financial services.

2.2 Theoretical Framework

This study is hinged on two relevant theories. They are the financial innovations theory and the supply-demand hypothesis

2.2.1 Financial Innovations Theory

The financial innovations theory is closely associated with the works of William L. Silber. His paper, "Towards a Theory of Financial Innovation", published in 1975, developed a systematic description of this theory. It was further advanced in 1983. According to Silber (1975; 1983), financial innovation theory describes how financial institutions develop new goods and technology in response to regulatory, cost, or market constraints. The theory further states that new financial services are innovated to reduce the impact of these constraints on firms. Thus, innovations such as Point-of-Sale (POS) terminals, mobile money platforms, Automated Teller Machines (ATMs), and most recently, Central Bank Digital Currencies (CBDCs) are products of adaptation to structural obstacles.

This theory is relevant to this study because it seeks to explain the rise of digital finance in Nigeria. Obstacles, including low banking penetration, cash dependencies, and restricted accessibility in rural areas, put pressure on financial institutions to develop new products. The successful adoption of digital finance instruments enables a consistent customer experience across various channels, including mobile apps, internet platforms, and physical locations

(Ononiwu et al., 2024). However, a criticism of this theory, according to Lerner and Tufano (2011), is that financial innovation introduces complexity and opacity, hence increasing system risk.

2.2.2 The Supply-Leading vs Demand-Following Hypothesis

This hypothesis, as introduced by Patrick (1966), explains the causal effect between development in digital finance and macroeconomic performance. The supply-leading hypothesis posits that development in the financial sector precedes and influences development in the real sector of the economy, while the demand-following hypothesis posits that development in the financial sector responds to growth in the real sector.

This hypothesis is particularly important for the Nigerian situation, because research demonstrates that the finance-growth relationship is dynamic, rather than unidirectional. Periods of ICT and service expansion have raised demand for digital payment systems, and the development of digital finance infrastructure has boosted firms' activity and consumption. This hypothesis enables the study to examine whether macroeconomic performance influences demand for digital finance, whether digital finance in Nigeria stimulates growth by driving supply, or whether both dynamics coexist simultaneously.

2.3 Empirical Review

The bulk of the empirical review examines the impact of digital finance on macroeconomic performance, with a focus on Nigeria. It highlights areas of consensus, findings, and gaps by

highlighting national, regional, and international studies. For instance, Iwedi (2024) examined the dynamics between digital payment channels and Nigeria's economic growth. Quarterly data was used and the estimation techniques employed were the Ordinary Least Squares (OLS) and Granger Causality. Findings revealed that digital payments have transformative power in influencing economic growth in Nigeria.

In investigating the link between digital payments and economic growth, Aldaas (2021) studied the correlation between electronic payment transactions and economic growth worldwide. The study found no clear evidence to support or refute the link between e-payment systems and economic growth, indicating a country-specific issue.

Additionally, Suleiman, Nwala, and Jacob (2023) examined the effect of the electronic payment system on economic growth in Nigeria. The estimation technique employed was the Vector Error Correction Model (VECM) and Dynamic Ordinary Least Squares regression for in-depth analysis. Key findings revealed that point-of-sale and mobile payment channels are significant drivers of economic growth in Nigeria, while web-based payment channels have an insignificant effect on economic growth.

Additionally, Okoyeuzu et al. (2019) investigated the impact of electronic payment channels on financial inclusion in Nigeria. The study employed the Autoregressive Distributed Lag (ARDL) model as the estimation technique. The study's findings revealed a positive and significant relationship between digital financing channels and financial inclusion in Nigeria.

In a similar study, Okoyeuzu and Isa (2020) investigated the impact of foreign investments (foreign direct investment (FDI), foreign portfolio investment (FPI), and foreign loans) on the development of digital finance in Nigeria, using the ARDL estimation technique. Results from the study revealed that foreign investment flows act as drivers for digital finance in Nigeria.

A further study by Ferreira (2021) employed the panel Granger causality estimation technique to examine the direction of the relationship between all nine IMF financial development indices and real GDP growth. The results confirm the existence of bidirectional causality, although not with the same statistical robustness for all the IMF indices.

Furthermore, in a bi-directional relationship, Adeyeye et al. (2015) investigated whether the supply-leading hypothesis holds in a developing economy, focusing on Nigeria. The research employed an ex post facto research design. The main econometric tool was the Granger Pairwise causality test. Findings revealed that GDP predicted three measures of financial development (financial depth, credit allocation by banks, and credit to the private sector), while only two measures (financial depth and credit allocation by banks) produced a feedback response to GDP.

In analyzing the relationship between digital finance and employment in Nigeria, Ogundimu et al. (2024) employed the Ordinary Least Squares method to analyze the data using E-views. The study revealed a significant relationship between remita and the employment rate in Nigeria. The study, therefore, concluded that digital finance has a significant impact on the employment rate in Nigeria. The study therefore recommends that Government agencies should actively promote the development of digital finance and focus on the role of digital finance in improving the consumption level of low and middle-income families and underdeveloped areas.

2.4 **Summary of gaps in the Literature**

This bidirectional relationship highlights the importance of understanding digital finance within Nigeria's broader macroeconomic context. Growth in GDP, employment, investment, and structural transformation drives the development of more digital financial innovations and services, while advancements in the financial sector broaden the levels of savings, consumption, employment, and

investment throughout the economy. Studies by Suka and Samuel (2024), Aigbovo and Izekor (2024), Iwedi (2024), Onwere and Oke (2023), and Ramos and Olweny (2021) have empirically analyzed the impacts of digital finance on economic growth and development. However, little attention has been placed on the two-way relationship between digital finance and the macroeconomy in Nigeria. Hence, this study aims to fill the gap by examining the bidirectional relationship between the growth of digital finance and the Nigerian economy as a whole. In addition to this, the study will utilize a dynamic model, such as the SVAR technique, which will link digital finance indicators with macroeconomic variables specific to Nigeria.

3. Data and Methodology

3.1 Research Methodology

The study employed an ex-post facto research design to analyze the direction of impact and relationship between digital finance and Nigeria's macroeconomic performance from the first quarter of 2012 to the fourth quarter of 2024, drawing on data from the Central Bank of Nigeria Statistical Bulletin and the National Bureau of Statistics. The model employed in this study is the Structured Vector Autoregression (SVAR), originally introduced by Christopher Sims (1980) and further developed by Blanchard and Watson (1986), because it considers the identification of economic shocks through impulse response functions to trace the presence of a digital adoption shock. This approach is adopted because it analyzes dynamic relationships between multiple time series, incorporates and identifies structural shocks. Despite the model's linear assumption, it accurately captures interdependence and shock timing, making it suitable for this study. This will aid in understanding how unexpected changes in one variable impact other variables in the system. The estimation technique to be used is the Generalized Method of Moments (GMM) approach, which identifies structural shocks and enables the use of instrumental variables (IVs) to address measurement errors or omitted variables. Since the SVAR is attentive to ordering, the variables will be ordered as follows: (1) Digital Finance Index, (2) Real GDP, (3) Inflation, (4) Monetary Policy Rate, and (5) Final Consumption Expenditure of Households.

This study adapts the model of Igoni et al. (2021) in their analysis of the linkage between electronic transactions and Nigeria's stock market performance.

$$MCAPr = f(ATMr, WEBr, NIPr, POSr) \quad (3.1)$$

where;

MCAP is Market capitalization

ATM is Automated Teller Machine

WEB is the Internet

NIP is NIBSS Instant Payment

POS is Point of Sale

However, for this current study, the model is adopted to include the digital finance index (DFI), which is a weighted average of various payment channels in Nigeria, after normalization. Then, this study introduced variables that measure macroeconomic performance, such as Real Gross Domestic Product (RGDP), Consumer Price Index (CPI), Final Consumption Expenditure of Households and Monetary Policy Rate (MPR).

The functional form of the model is given as;

$$DFI = f(RGDP, CPI, MPR, FCEH) \quad (3.2)$$

Table 1: Description, sources, and measurement of variables

Variables	Brief Description	Sources	Measurement
DFI	Digital Finance Index	CBN Quarterly Statistical Bulletin	Weighted average of the normalized form.
RGDP	Real Gross Domestic Product	CBN Quarterly Statistical Bulletin	N' Million
CPI	Inflation	National Bureau of Statistics	Monthly average
MPR	Monetary Policy Rate	CBN Quarterly Statistical Bulletin	% Percentage
FCEH	Final Consumption Expenditure of Households	National Bureau of Statistics	N' Million

Source: *Authors' compilation 2025*

3.2 Technique of Estimation

This study employed SVAR to assess the association between digital finance and macroeconomic performance in Nigeria. According to Enders (2015), the SVAR model's goal is to identify the linkages between variables and their responses to economic and structural shocks, rather than estimating parameters. SVAR models provide information on cause-and-effect linkages that are not obvious in the reduced-form VAR. This can be accomplished by separating the underlying shocks, determining restrictions, and estimating how variables respond to them over time. In essence, the reduced form VAR model views each variable as a function of its own past values as well as those of the other variables in the model. However, the structural VAR model allows us to investigate the causal relationships between variables and the impact of shocks on other variables. According to the theory, the SVAR model employs both short-run and long-run constraints.

The basic form of the VAR model can be described in its reduced form as:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t \qquad (3.3)$$

Where;

y_t is the vector of endogenous variables at time t, with n being the number of variables in the system.

A_i is the coefficient matrix for the autoregressions, which captures the relationship between the variables at different lags. For each i, where i = 1,2 ... , p. The matrix A_i is n × n, a square matrix.

y_{t-i} represents the lagged values of the endogenous variables at time t − i.

u_t is the unobserved error term, which is an n×1 vector with

The Structural Vector Autoregressive Model, in its structural form and time lag, p, is introduced below;

$$Ay_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + Bu_t \qquad (3.4)$$

$$y_t = A^{-1}A_1 y_{t-1} + \ldots + A^{-1} A_p y_{t-p} + A^{-1} B\varepsilon_t \qquad (3.5)$$

Where;

The structural matrix, A, captures the relationship between variables and how each variable

responds to the shocks in the system.

The matrix B represents the model's parameters in a structural form.

ε_t represents the structural error, which is an n x 1 vector and assumed to be orthogonal.

VAR (ε_t) represents a diagonal matrix, with the diagonal members being the structural disturbance variance.

It is necessary to impose certain restrictions because it is believed that shocks cannot be precisely detected. In order to do this, it is customary to multiply Eq. (3.2) by A^{-1} which results in the following relationship between the structural disturbances and the reduced-VAR disturbances:

$$u_t = A^{-1} B\varepsilon_t \qquad (3.6)$$

Imposing of Restrictions

According to Sims (1980), in order to recover the unobservable relevant shocks (εt) from the observable reduced form innovations, we must consider a structural VAR representation and impose a set of restrictions. Following the study by Bala and Ali (2017), the Structural Vector Autoregressive form is specified thus:

$$A_0 y_t = \Sigma^{p}_{i=1} A_i y_{t-1} + B\varepsilon_t \qquad (3.7)$$

Where;

Where A_0 shows the immediate effects; A_i is the lagged effects matrix and B captures the structural shocks.

Hence, the number of restrictions imposed is given as:  (3.8)

In Cholesky's restriction, we assume that some coefficients have a value of zero. While U_{1t} immediately influences the other variables simultaneously, U_{2t} only affects variables 2, 3, 4, and 5. According to the Cholesky decomposition, this suggests that u_1 has a direct and immediate effect on all variables (1, 2, 3, 4, and 5), U_{2t} can only affect variables 2, 3, 4, and 5, but not variable 1, and U_{3t}, U_{4t}, and U_{5t} affect only their respective variables and those that come later in the ordering (Holtemöller, 2002).

The model will be evaluated using the Generalized Method of Moments (GMM), a robust estimation approach that addresses variable endogeneity and permits the inclusion of lagged variables as instruments.

4. Results and Discussions

4.1. Descriptive Statistics

Descriptive statistics include the mean, median, maximum, minimum, standard deviation, skewness, kurtosis, and Jarque-Bera test. Running descriptive statistics is important since it allows the researcher to understand the distribution of the data being used.

Table 2: Descriptive Statistics

	DFI	RGDP	CPI	FCEH	MPR
Mean	0.199	17554.50	14.672	10723194	13.700

Median	0.087	17525.50	12.630	10770142	13.000
Maximum	0.799	22111.00	33.950	14747327	25.750
Minimum	0.0003	14106.00	7.830	4623857	11.330
Standard Deviation	0.227	1694.10	6.063	1867492	2.283
Skewness	1.093	0.399	1.301	-0.6779	2.387
Kurtosis	2.944	3.1258	4.565	4.4408	9.229
Jarque-Bera	9.969	1.366	19.216	8.154	128.366
Probability	0.007	0.505	0.00007	0.0169	0.00000
Observations	50	50	50	50	50

***Source**: Author's computation (2025)*

Table 2 provides descriptive data for the variables DFI, RGDP, CPI, MPR, and FCEH. The mean and median values fall within their respective ranges of greatest and minimum values, indicating a consistent distribution of the data. The majority of variables have skewness near zero, with the exception of CPI and MPR, which have positive skewness of 1.30 and 2.38, respectively, indicating infrequent inflation spikes and times of severe monetary policy tightening for MPR.

FCEH has a modest negative skew of -0.68, indicating that lower consumption periods occur more frequently, potentially owing to income shocks or inflationary pressures.

The kurtosis values for DFI and RGDP are close to the typical threshold of 3, indicating a distribution that is somewhat normal. However, CPI and FCEH have greater kurtosis values (4.56 and 4.44, respectively), indicating that these variables are subject to more severe variations, with CPI showing substantial volatility in inflation and FCEH reflecting big changes in consumption. MPR (9.23) is strongly leptokurtic, indicating significant fluctuations in monetary policy rates over time, which often accompany macroeconomic instability. The Jarque-Bera test indicates that the distribution of RGDP is normal, with p-values greater than 0.05. However, the other variables with a p-value less than 0.05 reject the null hypothesis of normality, suggesting that CPI, for example, deviates considerably from normalcy, mostly due to its volatility and the occurrence of extreme inflationary periods.

Overall, the results suggest that macroeconomic stability in Nigeria is fragile, primarily due to fluctuations in the Consumer Price Index (CPI) and the Monetary Policy Rate (MPR). This volatility poses challenges for policymakers, as regulating inflation in a steady and predictable manner is crucial for economic stability, particularly in a growing country like Nigeria, where inflationary shocks can rapidly impact real income levels and consumption patterns. In summary, whereas indicators such as RGDP and FCEH are relatively stable, the CPI and MPR remain highly unpredictable, posing considerable problems to Nigeria's economic planning and stability. The periodic increases in debt financing and inflation emphasize the importance of efficient fiscal and monetary policy in managing growth, investment, and consumption.

4.2. Unit Root Test

Table 3: Unit Root Test Result

Variables	ADF Test	Critic	P-	Order of	Remark

		al Value	Value	Integration	
LDF	-10.441	-3.502	0.000	I(1)	Stationary
LRGDP	-30.089	-2.923	0.000	I(1)	Stationary
LCPI	-3.757	-3.506	0.028	I(1)	Stationary
LFCEH	-5.837	-2.927	0.000	I(1)	Stationary
MPR	-3.925	-2.922	0.004	I(1)	Stationary

***Source**: Author's computation (2025)*

This study utilized time series data, which often exhibit non-stationarity and can lead to erroneous regression results if not properly handled. The unit root test findings revealed that, according to the ADF test statistics, all variables were non-stationary at levels. The ADF test results exceed the crucial levels at the 5% level of significance. As a result, after calculating the initial difference, these variables were determined to be stable, suggesting that they are integrated at order 1.

4.3. Lag Selection

Table 4: Lag Length Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1137.980	NA	7.93e+15	50.799	50.999	50.873
1	-1100.921	64.235	4.68e+15	50.263	51.467	50.712
2	-1062.241	58.449	2.66e+15	49.655	51.863	50.478
3	-997.9528	82.860	5.19e+14	47.909	51.120	49.106
4	-946.9030	54.453	2.05e+14	46.751*	50.966*	48.322*

***Source**: Author's computation (2025)*

Before running the SVAR (Structural Vector Autoregressive) estimate, the suitable lag length must be determined, as the model's outcomes are sensitive to the lag chosen. Based on these parameters, the ideal lag duration was determined to be Lag 4. Lag 4 had the lowest Akaike Information Criterion (AIC)

value of 46.751, indicating an optimal balance between model fit and complexity. Thus, Lag 4 was chosen for the SVAR estimate, ensuring that the model is properly specified and that the findings are both accurate and interpretable for future studies.

4.4. Stability Test

Before moving on to the Impulse Response Functions (IRFs) and variance decomposition, it is imperative to ensure the Structural Vector Autoregressive (SVAR) model is stable. Stability is a critical assumption in the SVAR framework, as it ensures that the system returns to equilibrium after any shocks, thereby preventing explosive or unrealistic reactions. To check for stability, we examined the roots of the model's characteristic equation, which are represented by eigenvalues Inverse Roots of AR Characteristic Polynomial

on the stability graph. These eigenvalues are shown on the complex plane, with the unit circle serving as the baseline. For the model to be stable, all the eigenvalues must be inside the unit circle, indicating that the system will not diverge over time.

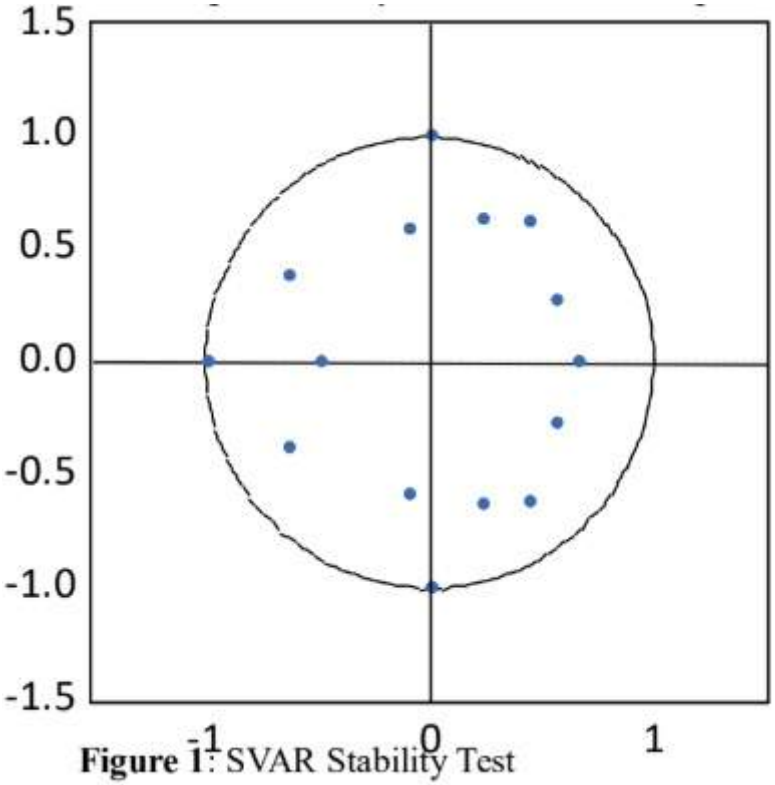


Figure 1: SVAR Stability Test

The stability test results, shown in Figure 1, indicate that all the blue dots (eigenvalues) lie within the unit circle. This demonstrates that the SVAR model is stable, which means that the system will adjust and return to equilibrium following a shock, and that the calculated relationships between the variables are reliable.

4.4. Impulse Response Function (IRF)

The application of the generalized impulse response function ensures that the outcomes are independent of the variable ordering, allowing for a deeper understanding of how digital money affects the Nigerian economy. The impulse response function (IRF) illustrates how a one-standard deviation shock to a single endogenous variable impacts the current and future values of all variables in the model. This study employs the IRF to examine how innovations in digital finance (LDF) impact Real GDP (LRGDP), Consumer Prices (LCPI), Monetary Policy Rate (MPR), and Household Consumption

Expenditure (LFCEH), and vice versa. In other words, how shocks to important macroeconomic variables impact Nigeria's adoption rate of digital finance over a ten period period. The solid line represents the estimated response, while the dotted lines indicate the standard error bands, which show the confidence interval for each response.

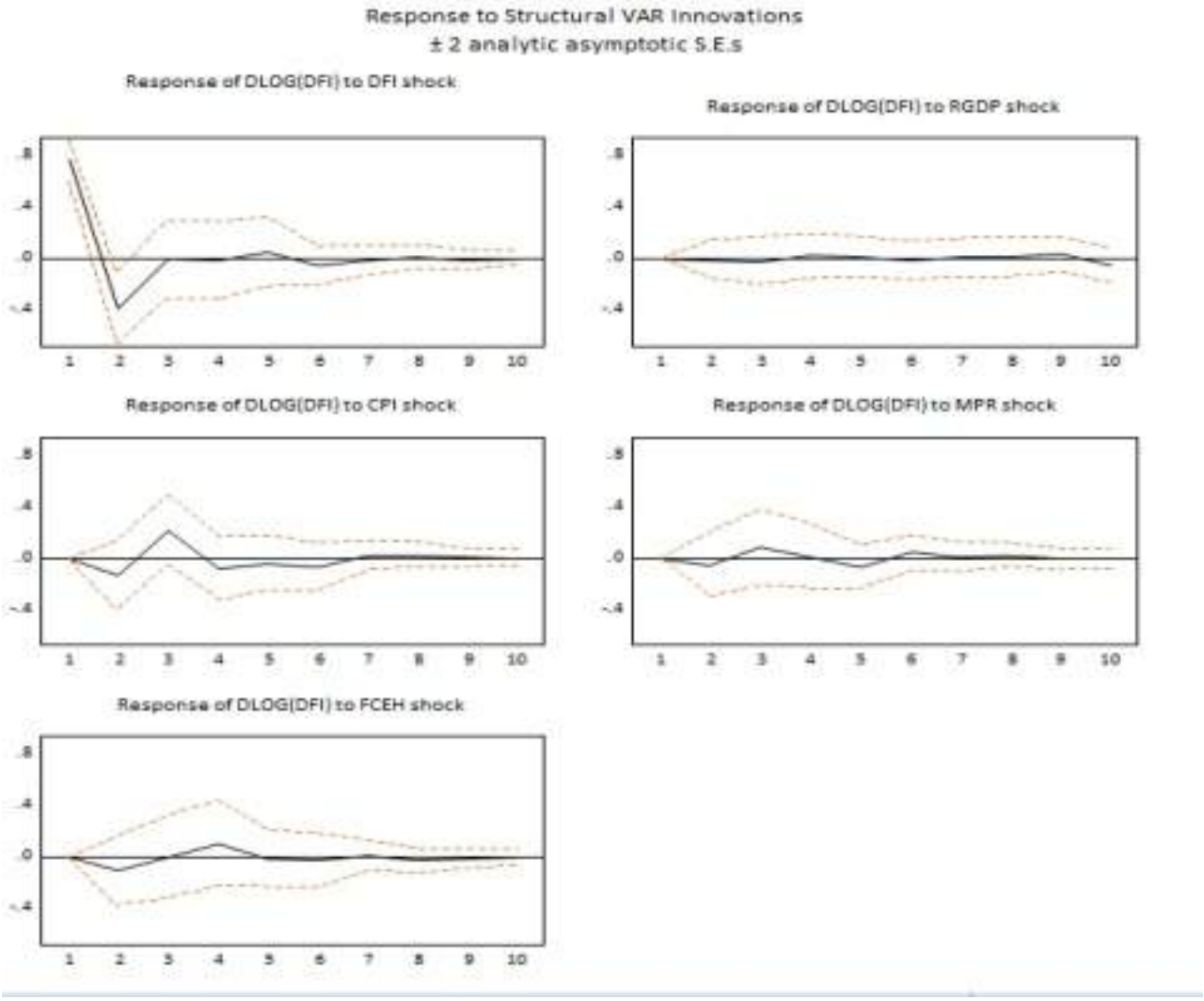


Figure 2: Response of Digital Finance (DF) to a one-time shock in the macroeconomic variables

The one-unit response of DFI to itself shows a high initial positive reaction in the first period, peaking at period 2, then gradually declining to zero. The effect stabilizes after a few periods, demonstrating that digital banking is highly impacted by its own inventions in the short term, but this impact diminishes over time. In Nigeria, a policy shift or innovation in digital payment systems has an immediate positive impact on the digital finance ecosystem, such as increasing usage of digital payment platforms or financial inclusion initiatives. However, this effect lessens with time, implying that after initial adoption, the rate of change reduces as the system stabilizes. Economically, this indicates that digital finance innovation can stimulate the economy by increasing access to finance and promoting inclusivity; however, the short-term boost is typically followed by stabilization as the system adapts and reaches full capacity.

The DFI response to the RGDP shock exhibits tiny variations at first, followed by a slight positive response towards period 6, before stabilizing. This suggests that economic growth has a minimal impact on digital finance over time. This indicates that, while real GDP growth may boost financial activity, its impact on the adoption of digital finance is more gradual and less pronounced. The relationship is

modest, likely due to the time lag in technological and infrastructure changes needed for widespread digital finance adoption in Nigeria.

In the first and second periods, the DFI's reaction to the CPI shock begins at a negative value. The third period sees a positive increase, followed by a decline and oscillation around zero in the subsequent periods. The response stabilizes around zero by periods 7 through 10, suggesting that while inflationary shocks (CPI) initially have a detrimental effect on digital finance, this effect gradually lessens. The negative initial response suggests that inflation (as measured by the CPI) in Nigeria may lead to initial declines in the adoption of digital finance, likely due to consumers prioritizing immediate consumption or coping with rising prices. The durability of digital banking systems, which progressively adapt as inflation stabilizes, is demonstrated by the rapid fading of this effect. The adoption of digital banking becomes less vulnerable to inflation over time, indicating that as the economy normalizes or adapts to price fluctuations, consumers may return to digital platforms.

DFI's reaction to MPR shock is initially slightly negative, but in the second and third periods, it becomes positive. After that, during periods five and six, it oscillates slightly above and below zero until leveling off at zero during periods seven through ten. The total reaction suggests that MPR shocks have a moderate and steady impact on digital finance. The Monetary Policy Rate (MPR) influences overall financial conditions, borrowing costs, and liquidity, all of which impact digital finance. In this scenario, a positive MPR shock, which represents an increase in the rate, elicits a minor negative reaction in digital finance, likely because consumers are seeking more efficient ways to manage their finances in a tightening market. However, the reaction is moderate and stable over time, indicating that monetary policy has a consistent but not significant impact on the adoption of digital finance.

DFI's response to the FCEH shock was negative from periods 1 to 3, indicating a negative influence of household consumption expenditure (FCEH) on digital finance. The response then turns positive in period 4 and remains modestly positive for the remainder of the periods, eventually stabilizing around zero. The initial negative response indicates that increases in household consumption expenditure may limit digital finance utilization in the short term, possibly due to a shift in focus away from engaging with digital payment systems and towards immediate spending demands.

However, as purchasing patterns change, the favourable response suggests that digital finance adoption will expand over time, most likely due to greater integration of digital platforms into daily spending habits. After a period of initial adjustment, the influence of consumption on digital finance appears to level off, as indicated by the stabilization around zero.

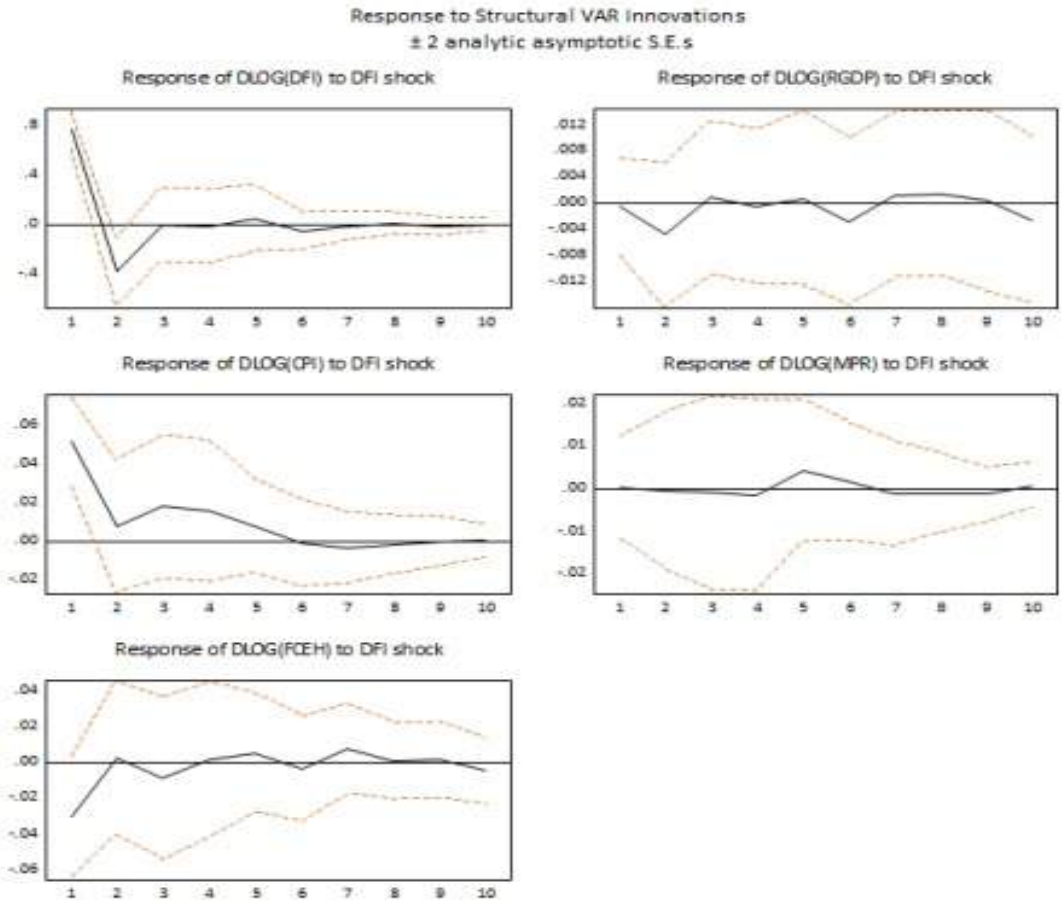


Figure 3: Response of macroeconomic variables to one S.D. shock in Digital Finance (DF)

A shock to digital finance (DFI) has relatively minor and transient effects on real GDP (RGDP), according to the impulse response graph. RGDP reacts negatively in the first period, suggesting that an unanticipated rise in digital finance first modestly lowers output. RGDP varies extremely little in both positive and negative directions between periods 2 and 7, indicating that the economy recovers fast and that the effects of the shocks do not result in significant changes in real output. The response stays near zero for periods 8 to 10, indicating that the shock's effects eventually fade away.

Economically, this pattern suggests that digital finance shocks have a minimal impact on Nigeria's real GDP. While DFI is crucial for financial access, its immediate effect on output is limited, possibly because the transition from digital financial usage to productive economic activity requires time, complementary infrastructure, and broader macroeconomic stability.

The CPI reaction to a DFI shock reveals an initial sharp spike in inflation in period one, followed by a fall in period two through four, demonstrating that digital finance expansion first exerts upward pressure on prices. By period 5, the shock effect begins to decrease, and from periods 6 to 10, CPI bounces around zero, indicating that the shock's inflationary influence fades and stabilizes. This suggests that, while digital finance may introduce transient inflationary pressures, these effects are likely to be temporary and may not extend to long-term inflation. This demonstrates that although digital finance may cause initial price increases, its long-term effects on Nigerian inflation remain negligible, indicating the need for policies that control short-term inflation without hindering the expansion of digital finance.

MPR is initially slightly positively impacted by digital finance shocks (DFI), indicating a short term

monetary policy response to shifts in financial activity. The negative reaction to digital finance shocks in period 4 raises the possibility that monetary policy would initially tighten, possibly as a result of growing inflationary fears or changing financial market expectations. The positive increase from period 4 to period 6, however, suggests that as digital finance stabilizes, it may have a slightly favorable impact on monetary policy, possibly indicating increased financial stability or improved central bank liquidity management. The impact of digital financial shocks on monetary policy gradually diminishes and stabilizes close to zero, as evidenced by the minor reduction starting in period 7.

In period 1, FCEH's response to a DFI shock is initially negative, but in period 2, it sharply increases and enters positive territory. The reaction remains favourable in periods 4 and 5, with little variation above zero, indicating a somewhat favourable impact on household consumption. The reaction remains positive in period 7, indicating further changes in household purchasing patterns. The response, however, stabilizes in periods 8 and 9 before turning negative in period 10.

This implies that Nigerian household spending is initially boosted by digital finance due to easier access to financial services, but the benefit eventually wanes. The long-term negative response in period 10 may suggest that the digital financial shock loses its benefits on household consumption as it normalizes, possibly due to changes in spending habits or the state of the economy.

4.5. Variance Decomposition

The variance decomposition reflects the percentage contribution of each variable's shock in explaining the variation in other variables. It analyzes the relative importance of each shock in explaining the movement in the variables.

Table 5: Variance Decomposition of Digital Finance

Period	S.E.	DFI shock	RGDP shock	CPI shock	MPR shock	FCEH shock
1	0.770	100.000	0.000	0.000	0.000	0.000
2	0.875	96.170	0.003	2.162	0.378	1.287
3	0.905	89.899	0.051	7.657	1.190	1.203
4	0.916	87.829	0.108	8.241	1.185	2.638
5	0.921	87.224	0.131	8.327	1.692	2.627
6	0.927	86.483	0.160	8.812	1.888	2.657
7	0.927	86.403	0.169	8.863	1.895	2.670
8	0.929	86.120	0.182	8.922	1.945	2.752
9	0.929	86.063	0.320	8.907	1.958	2.753
10	0.931	85.804	0.619	8.881	1.952	2.745

Source: Author's compilation in EView

The variance decomposition of DLOG (DFI) reveals that, by the tenth period, over 85% of the volatility in digital finance (DFI) may be attributed to its shocks. This highlights how digital banking advancements have a significant impact on Nigeria's own trajectory. Economic factors, such as inflation (CPI) and economic growth (RGDP), increasingly contribute to the explanation of changes in DFI as the

periods progress. CPI is especially important as it rises from 2.16% in period 2 to 8.88% by period 10. This implies that the adoption and use of digital financial services are influenced by macroeconomic factors such as inflationary pressures as digital finance systems develop.

Monetary policy (MPR), which initially has a minimal impact on DFI, gains relevance with time, highlighting the role of interest rates and liquidity management in building the financial environment for digital finance. This growing effect suggests that as digital finance becomes more integrated into the broader economy, monetary policy will play a larger role in its dynamics. Meanwhile, household consumption expenditure (FCEH) remains a little but consistent contributor to the variance in DFI, indicating that, while digital finance may influence consumer behaviour indirectly, it does not yet have a significant direct impact on consumption patterns.

In summary, the findings indicate that digital finance innovation is the primary driver of its own growth; however, macroeconomic factors, particularly inflation and economic growth, are beginning to have an increasing impact on its evolution over time. This demonstrates how digital finance is becoming increasingly integrated into the broader economic environment, with monetary policy and inflationary pressures playing a greater role in shaping its long-term evolution

4.6. **Generalized Method of Moments**

Hansen (1982) developed the Generalized Method of Moments (GMM), a reliable econometric estimation method that uses moment conditions, which are expectations derived from economic theory, to produce reliable and effective parameter estimates even when endogenous regressors are present. By permitting the employment of several instruments that meet the orthogonality constraint between the instruments and the error term, GMM generalizes the instrumental variable (IV) approach. GMM is frequently used in macroeconomic models because it guarantees efficiency in small samples and solves simultaneity bias. This study employs GMM to account for potential endogeneity between macroeconomic factors and digital finance (DFI), ensuring objective and reliable estimates. The validity of the instruments is tested using the J-statistic. The rule of thumb is that a non-significant p-value indicates that the model is appropriately described,

and the instruments are valid.

Table 6: Generalized Method of Moments

Variable	**Coefficient**	**Std. Error**	**t Statistic**	**Prob.**
C	-69.59	13.44	-5.18	0.00
LRGDP	10.65	2.76	3.86	0.00
LCPI	3.02	0.411	7.32	0.00
LMPR	-3.85	2.04	-1.89	0.066
LFCEH	-2.15	1.54	-1.39	0.17
R-squared	0.69	Mean dependent var		-2.46
Adjusted R-squared	0.67	S.D. dependent var		1.63
S.E. of regression	0.94	Sum squared resid		37.73
Durbin-Watson stat	1.03	J-statistic		9.75

Instrument rank	11	Prob(J-statistic)	0.14

***Source**: Authors' computation in Eviews*

The result in Table 9 reveals the R-squared value of 0.69, indicating that approximately 69% of the variation in digital finance is explained by the variations in the selected macroeconomic variables, while the J-statistic, with a P-value of 0.14, confirms that the chosen instruments are valid since the null hypothesis of instrument exogeneity cannot be rejected.

The coefficient of real GDP is 0.65, which is positive and statistically significant at the 5 percent level, implying that economic growth significantly drives the expansion of digital finance in Nigeria. This finding highlights the strong correlation between macroeconomic performance and digital financial deepening, indicating that higher levels of economic activity increase access to and utilization of digital platforms. Furthermore, LCPI is positively related to the level of digital finance and is also significant at the 5 percent level. This suggests that digital finance is positively correlated with inflationary trends. As consumers and businesses seek effective payment methods to manage growing transaction costs, this may signal a greater reliance on digital financial channels during periods of inflation. Nonetheless, at a 5 percent significance level, the monetary policy rate and household final consumption exhibit negative correlations; however, these correlations are not statistically significant. This suggests that the growth of digital finance may be limited by strict monetary policy.

In the fintech ecosystem, higher interest rates decrease digital borrowing and investing activities by reducing credit availability. The household consumption expenditure (LFCEH) result, on the other hand, indicates that digital finance has little effect on Nigerian consumer behaviour. This could be due to adoption gaps in infrastructure and limited penetration in low-income segments, such as rural areas.

The results, however, show that digital finance is both a driver and a reflection of macroeconomic developments. Its increase is strongly linked to economic expansion and price conditions, whereas monetary policy has a mitigating effect. The insignificance of household consumption shows that Nigeria's digital finance adoption trajectory is shaped by broader economic fundamentals rather than short-term consumer behaviour. The GMM results emphasize the necessity of preserving macroeconomic stability, supporting inclusive growth, and enacting supportive financial policies to continue digital financial development.

5. Conclusion

This study examined the interaction between digital finance and Nigeria's macroeconomic environment using SVAR and GMM techniques. The results indicate that digital finance responds strongly to inflation and economic activity, with a positive but modest influence on real GDP. Variance decomposition further reveals that digital finance is largely driven by its own shocks, with inflation becoming a key long-run contributor. The GMM estimates confirm that growth and inflation significantly support the expansion of digital finance, whereas monetary policy and consumption play weaker roles in this context. Overall, the results show that macroeconomic stability and digital finance are closely related in Nigeria. Policymakers should prioritize price stability, increase investments in digital infrastructure, and uphold stable monetary policy in order to increase its influence. By taking these steps, digital finance will be better able to contribute to equitable and sustainable economic growth.

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Intelligent System for Waste Management with Deep Learning Techniques

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OUTLINES

1. Background of Study.
2. Aim of the Study.
3. Research Objectives.
4. Research Questions
5. Literature Reviews
6. Methodology
7. Result
8. Recommendation
9. Reference

Background of Study.

Among the myriad environmental challenges confronting developing nations, the inadequate management of solid waste has emerged as a critical focal point (Godfrey et al., 2019; World Bank, 2021.

According to facts from Statista, over 2.01 billion metric tons of Municipal Solid Wastes (MSW)) are generated worldwide every year. This issue has gained such prominence that it has become a widely acknowledged environmental axiom.

Current environmental policies and decision-making processes predominantly concentrate on refining technical approaches and strengthening formal regulatory frameworks governing waste disposal practices (World Bank, 2021.

However, this narrow focus may overlook other crucial aspects of comprehensive waste management strategies.



Metric Tonnes Conversion
1 Tipper = 13 Metric tonnes
2.01 billion tonnes = 154,615,385 tippers
32 million tonnes = 2,461,538 tippers



Statement of Problem



- Waste management infrastructure
- Poor behavioral attitude
- Unskilled waste collection workforce
- Indiscriminate dumping and burning of plastic wastes
- Poor awareness
- Inadequate funding

Health Risks

Improper waste management practices can lead to the spread of diseases, such as cholera and other waterborne illnesses.

Environmental Impact

The lack of proper waste sorting leads to environmental degradation, including pollution of land and water bodies.

Inefficiency

Manual waste sorting is a labor-intensive process that is prone to errors and inefficiencies.





Research Aim

The primary aim of this research is to develop and evaluate an automated waste recognition and classification system using deep learning techniques. This system will enhance the efficiency and accuracy of waste management processes, leading to improved recycling rates and a reduced environmental impact.

Research Objectives



1. Model Accuracy
The research aims to identify a deep learning model that accurately classifies different waste types, achieving high precision and minimizing errors.

2. Real-World Training
The effectiveness of training the model with real-world waste samples will be evaluated to improve waste identification, classification, and processing accuracy.

3. Algorithm Comparison
The performance of various deep learning algorithm architectures will be compared to determine their effectiveness in accurately classifying waste types.

4. Model Optimization
The top-performing deep learning model will be optimized for enhanced classification accuracy, robustness, and efficiency in real-world waste management scenarios.



Research Questions

1. Which Deep Learning-based model most accurately classifies different waste types, achieving the highest level of precision while minimising classification errors?

2. To what extent does training with real-world waste samples improve the accuracy of waste identification, classification, and processing in Deep Learning-based models?

3. What differences do various Deep Learning architectures exhibit while comparing their performance and accuracy when classifying different types of waste?

4. What optimization techniques can be applied to the top-performing Deep Learning-based model to enhance its classification accuracy, robustness, and efficiency in real-world waste management scenarios?

Literature Review

Authors	Objectives	Methodology	Findings	Gap
Ahmed et al. (2023)	To classify garbage using advanced CNNs and pre-trained models.	Used DenseNet169, MobileNetV2, ResNet50V2 on a benchmark dataset.	Pre-trained models significantly outperformed a simple CNN, with ResNet50V2 achieving 98.95% accuracy.	Focused on high-accuracy, complex models without considering their computational cost or performance on smaller, real-world datasets.
Majchrowska et al. (2022)	To develop a waste detection and classification method using deep learning.	Used EfficientDet-D2 for localization and EfficientNet-B2 for classification on a comprehensive dataset.	Achieved ~70-75% accuracy for detection and classification, and up to 92% with a custom Multi-layer Hierarchical System (MHS).	The study highlighted the need for robust models but did not explore the performance of traditional, less complex models like SVM as a baseline for situations with limited data.



Literature Review

Sakib et al. (2024)	To improve trash classification accuracy with a novel deep learning model.	Proposed a novel ECCDN-Net model, combining DenseNet201 and ResNet18, trained on 24,705 images.	ECCDN-Net achieved 96.10% accuracy, outperforming other pre-trained models.	Relied on a very large dataset (24,705 images) and complex, custom architectures, which are often impractical in resource-constrained environments.
Mosarrof et al. (2024)	To classify waste using a multi-stage ML approach for single and multi-label tasks.	Introduced GCDN-Net and evaluated it on the GIGO dataset (25,000 images).	Achieved 95.77% accuracy in single-label classification and high precision/recall.	Similar to others, it demonstrated the power of deep learning on large datasets but did not address scenarios with limited data availability



Literature Review

1. Zhou et al. (2024) proposed an integrated method combining ResNet-50, YOLOv5, and weakly supervised CNN algorithms, achieving significant improvements in accuracy and efficiency.

2. Wang and Olugboja (2019) developed an intelligent waste material classification system using ResNet-50 and Support Vector Machine (SVM), achieving an accuracy of 87% on a trash image dataset.

3. Q. Zhang et al (2021) proposes a waste image classification model (CTR) based on ResNet18, which can use deep learning methods to separate different types of waste. The CTR model was tested using the TrashNet waste dataset, and the accuracy of waste classification reaches 95.87%.

Knowledge Gap/Limitation Summary

1. Real Local Based data was not used.
2. Regional differences in model performance.



Methodology

1

Data Collection

Real-world waste images were collected from four various locations within the University of Ibadan, including hostels, eateries, faculty buildings, and dump sites. Approximately 1,710 datasets were generated, with 70% used for training and 30% for testing.





2

Data Augmentation

Data augmentation techniques, such as rotations, flips, and scaling, were applied to increase the diversity of the training data and improve model generalization.







SVM Model Specification

Mathematical Formulation

Given a training dataset $\{(x_i, y_i)\}_{i=1}^{n}$, where:

- $x_i \in \mathbb{R}^d$ are the feature vectors,
- $y_i \in \{-1, 1\}$ are the class labels,
- w is the weight vector,
- b is the bias term.

The optimal hyperplane is found by solving:

$$\min_{w,b} \frac{1}{2}\|w\|^2$$

subject to:

$$y_i(w \cdot x_i + b) \geq 1, \quad \forall i$$

For non-linearly separable data, a kernel function $K(x_i, x_j)$ is used to map the data to a higher-dimensional space:

$$K(x_i, x_j) = \phi(x_i) \cdot \phi(x_j)$$

where $\phi(x)$ is the transformation function.

The decision function is:

$$f(x) = \text{sign}\left(\sum_{i=1}^{n} \alpha_i y_i K(x_i, x) + b\right)$$

where α_i are Lagrange multipliers.

DenseNet Model Specification

Mathematical Formulation

If $x_0, x_1, ..., x_L$ represent the feature maps of different layers, each layer receives inputs from all previous layers:

$$x_l = H_l([x_0, x_1, ..., x_{l-1}])$$

where H_l is a composite function (Batch Normalization, ReLU, and Convolution).

The transition layers reduce dimensionality using:

$$x_l' = \text{Pooling}(W_l x_l + b)$$

where W_l is the weight matrix and b is the bias.

The final prediction is obtained using a fully connected layer with Softmax:

$$p(y|x) = \frac{e^{Wy}}{\sum_k e^{W_k x}}$$

EfficientNet Model Specification

Mathematical Formulation

The scaling coefficient is:

$$d = \alpha^t, \quad w = \beta^t, \quad r = \gamma^t$$

where t is a user-defined parameter, and α, β, γ are scaling coefficients satisfying:

$$\alpha \cdot \beta^2 \cdot \gamma^2 \approx 2$$

The network follows a standard convolutional neural network structure with Mobile Inverted Bottleneck Convolution (MBConv) blocks:

$$y = \sigma(W \cdot (x \odot F(x)))$$

where $F(x)$ is a squeeze-and-excitation function, $\odot$ denotes channel-wise multiplication, and σ is the activation function.

The final classification uses Softmax:

$$p(y|x) = \frac{e^{W_i x}}{\sum_i e^{W_i x}}$$

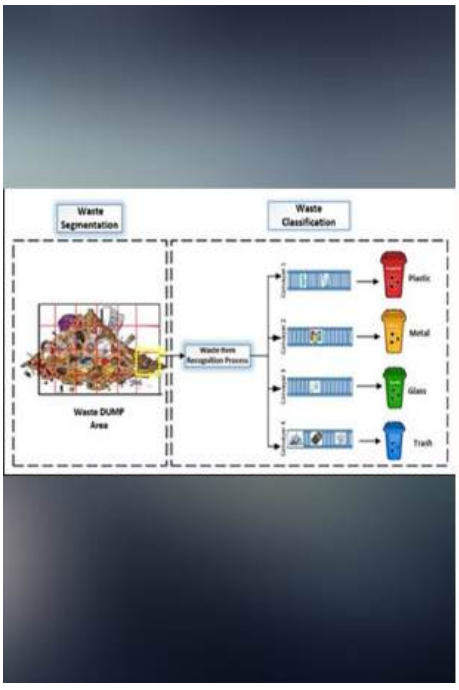


Results

Waste Database

This research created a set pace waste database (1,710) for the University of Ibadan, enabling waste logging and management for improved waste management practices.





Models Result
Classification Outputs

Models		Precision	Recall	F1 Score	Support
DenseNet	Food	0.99	0.67	0.80	147
	Paper	0.80	0.43	0.56	199
	Plastic	0.51	0.93	0.66	169
EfficientNet 80	Food	0.00	0.00	0.00	147
	Paper	0.39	1.00	0.56	199
	Plastic	0.00	0.00	0.00	169
SVM	Food	0.79	0.84	0.81	96
	Paper	0.76	0.74	0.75	134
	Plastic	0.75	0.73	0.74	112

Interpretation

Precision

Food (0.99): Almost all predicted "Food" samples were actually **Food**.
Paper (0.80): 80% of predicted "Paper" samples were correct.
Plastic (0.51): Only 51% of predicted "Plastic" samples were correct, meaning **many false positives**.

Recall

Food (0.67): The model identified **67%** of actual "Food" samples correctly.
Paper (0.43): The model only identified **43%** of actual "Paper" samples, meaning it **missed a lot**.
Plastic (0.93): The model correctly identified **93%** of all "Plastic" samples.

F1-score

The F1-score balances **precision & recall**. A **higher value** means better classification.

The **highest F1-score is for Food (0.80)**, indicating **better performance**.

Plastic (0.66) has a high recall but lower precision, meaning it often misclassifies **non-plastic as plastic**.



Model Confusion Matrices

- **Misclassification:** The model struggles to differentiate between the items. For example,
  Paper as Plastic (113, 0, 24)
  Food as Plastic (37, 0, 7)
  Plastic as Paper (11, 169, 22)
  Food as Paper (11, 147, 12)
- **Model Strength:** DenseNet to Plastics, EfficientNet80 to Paper and SVM to Paper.
- **Note:** Matrix arrangement
  Row 1, Column 1 Food
  Row 2, Column 2 Paper
  Row 3, Column 3 Plastic

DenseNet

$$\begin{bmatrix} 99 & 11 & 37 \\ 0 & 86 & 113 \\ 1 & 11 & 157 \end{bmatrix}$$

EfficientNet80

$$\begin{bmatrix} 0 & 147 & 0 \\ 0 & 199 & 0 \\ 0 & 169 & 0 \end{bmatrix}$$

SVM

$$\begin{bmatrix} 80 & 12 & 7 \\ 9 & 101 & 24 \\ 11 & 22 & 76 \end{bmatrix}$$

Using DenseNet as a Sample

Accuracy 66%: The model correctly classifies **66% of all waste samples**.

Plastic has the highest recall (0.93): this means it's well-detected but causes many **false positives (Type I error in Classification)**.

Paper is the most misclassified category (recall 0.43, many false negatives).

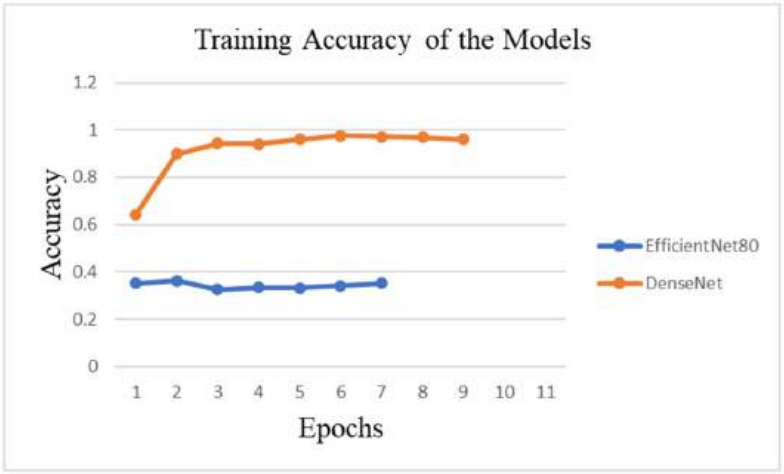
Interpretation

Overall Model Performance

Models		F1 Score	Support
DenseNet	Accuracy	0.66	515
EfficientNet80	Accuracy	0.39	515
SVM	Accuracy	0.77	342

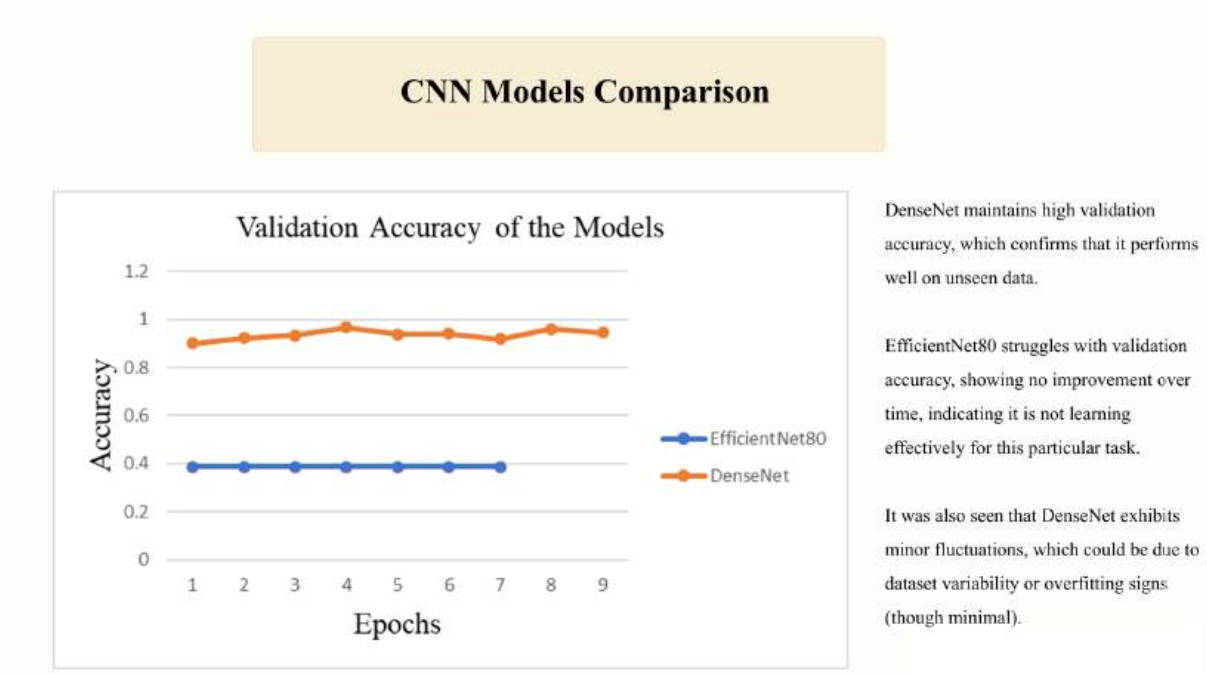
Models	Training Speed	Accuracy Level
DenseNet	Moderate	Good
EfficientNet80	Very fast	Poor
SVM	Optimum	Best

CNN Models Comparison



DenseNet significantly outperforms EfficientNet80 in training accuracy, indicating it is learning better from the dataset.

EfficientNet80's performance remains poor, which could be due to insufficient training data, or ineffective feature extraction for this specific dataset. Likewise, DenseNet stabilizes quickly.



5.3 Conclusion

In conclusion, this research demonstrates the potential of machine learning and deep learning techniques to transform waste management systems, particularly in developing countries like Nigeria. The findings highlight the importance of selecting the right model for the task, considering factors such as dataset size, computational resources, and the specific requirements of the application. While SVM emerged as the best-performing model in this study, the future of waste management lies in the integration of multiple techniques, including deep learning, IoT, and smart city technologies. By addressing the challenges identified in this research and building on its contributions, future work can pave the way for more sustainable and efficient waste management systems worldwide.

5.4 Contributions to Knowledge

This study makes several contributions to the field of waste management and machine learning:

i. Application of SVM in Waste Classification: The research demonstrates the effectiveness of SVM, a traditional machine learning algorithm, in waste classification tasks. SVM's ability to achieve high accuracy with a relatively small dataset makes it a viable option for waste management systems in resource-constrained environments.

ii. Evaluation of Deep Learning Models: The study provides a comprehensive evaluation of two state-of-the-art deep learning models, DenseNet and EfficientNet80, in the context of waste classification. The results highlight the strengths and limitations of these models, particularly in

scenarios with limited data.

iii. Real-World Dataset: The research utilized a real-world dataset collected from the University of Ibadan, making the findings more applicable to practical waste management scenarios in developing countries. This dataset can serve as a valuable resource for future research in this domain.

iv. Comparative Analysis: The study offers a detailed comparative analysis of SVM, DenseNet, and EfficientNet80, providing insights into the trade-offs between traditional machine learning and deep learning approaches for waste classification tasks.

5.5 Recommendations

Based on the findings of this research, the following recommendations are proposed:

i. Larger and More Diverse Datasets: Future research should focus on collecting larger and more diverse datasets to improve the performance of deep learning models. A larger dataset would help mitigate overfitting and underfitting issues, particularly for complex models like EfficientNet80.

ii. Hybrid Models: Combining the strengths of traditional machine learning models (e.g., SVM) with deep learning models could yield better results. For instance, SVM could be used for initial classification, while deep learning models could be employed for more complex waste categories.

iii. Real-Time Implementation: Future work should explore the real-time implementation of the proposed system using IoT-enabled smart bins and edge computing devices. This would enable real-time waste classification and monitoring, further enhancing the efficiency of waste management systems.

iv. Public Awareness and Education: To complement the technical solutions proposed in this study, there is a need for increased public awareness and education on proper waste segregation and recycling practices. This would ensure that the automated systems are used effectively and that the benefits of intelligent waste management are fully realized.

v. Policy and Governance: Governments and waste management authorities should consider integrating intelligent waste classification systems into their waste management policies. This would require investment in infrastructure, such as smart bins and IoT sensors, as well as training for personnel to operate and maintain these systems.

5.6 Limitations of the Study

While this research provides valuable insights into the application of machine learning and deep learning techniques for waste classification, it is not without limitations:

i. Dataset Size: The dataset used in this study was relatively small, which may have limited the performance of deep learning models. Larger datasets would be required to fully leverage the capabilities of models like EfficientNet80.

ii. Environmental Factors: The real-world environment introduced challenges such as mixed waste bins, varying lighting conditions, and weather factors, which affected the quality of the images and,

consequently, the performance of the models.

iii. Computational Resources: The study was constrained by limited computational resources, which restricted the ability to train more complex models or conduct extensive hyperparameter tuning.

iv. Generalizability: The dataset was collected from a single institution (University of Ibadan), which may limit the generalizability of the findings to other regions or waste management scenarios

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Anomaly Detection in Electricity Consumption Patterns in the Residential Areas of the University of Ibadan

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Abstract

Unmonitored consumption, billing discrepancies and energy wastage make it difficult for institutions to manage electricity in their residential areas. This study applies statistical and machine-learning methods to detect anomalies in electricity consumption in the residential areas of the University of Ibadan, using 12 years (2012–2023) of prepaid transaction records from the University's Works and Maintenance Department: 138,310 transactions from 1,411 accounts, worth ₦449.0 million in total. Monthly transaction values show a clear upward trend with seasonal fluctuations. Four detection methods flag between 3.0% (Isolation Forest) and 34.9% (interquartile range) of accounts, and 312 accounts (22.1%) are flagged under the study's consensus rule. K-means clustering, supported by hierarchical clustering and principal component analysis, separates three consumption groups: 90 high-consumption, highly variable accounts; 224 moderate accounts; and 1,097 low, stable accounts (77.7%). The high-consumption group departs most from typical residential behaviour and is the priority for investigation of possible meter tampering, faulty meters or bypassing. The study recommends targeted audits, cluster-based demand-side communication, real-time anomaly monitoring, richer data collection and the use of the clusters in load forecasting and maintenance planning.

Keywords: anomaly detection, electricity consumption, Isolation Forest, k-means clustering, smart metering, University of Ibadan

1. Introduction

Managing electricity consumption is central to the financial and environmental sustainability of universities. At the University of Ibadan, the residential areas account for a significant share of electricity demand, yet consumption there has been largely unmonitored, and the institution faces billing discrepancies and energy wastage. The spread of smart, prepaid metering has changed what is possible: every purchase of electricity now leaves a record, and over time these records form a large dataset that can show how consumption evolves and where it departs from normal behaviour.

This study uses 12 years of transaction data to detect anomalies in electricity consumption in the University's residential areas. It has three objectives: (i) to describe the temporal and behavioural patterns of consumption; (ii) to identify anomalous accounts using several complementary detection methods; and (iii) to classify accounts into consumption groups that can guide monitoring and demand-side management.

2. Literature Review

Residential electricity use follows recognisable daily, weekly and seasonal patterns, and smart-meter data can reveal household characteristics from these patterns (Beckel et al., 2014). Methods for detecting anomalies in such data have moved from simple statistical rules, such as z-scores and interquartile-range limits, towards machine-learning approaches. Unsupervised methods are particularly useful where confirmed cases of fraud or faults are scarce: the Isolation Forest isolates

unusual observations through random partitioning (Liu et al., 2008), and density-based clustering (DBSCAN) treats points in sparse regions as noise (Ester et al., 1996). Clustering techniques such as k-means (MacQueen, 1967) and hierarchical clustering are widely used to segment customers by consumption behaviour. Applications of these tools to institutional residential settings in Africa remain limited, and this is the gap the study addresses.

3. Data and Methods

The data come from the University of Ibadan Works and Maintenance Department and cover the recorded prepaid electricity transactions in the University's residential areas from 2012 to 2023: 138,310 transactions from 1,411 accounts, with a total value of ₦449,005,481.91. Each record contains the account number, meter number, tariff class, amount paid and the date and time of the transaction. Transactions were aggregated to account level to construct consumption features: average, minimum and total consumption, the standard deviation of consumption, and the number of transactions.

Temporal patterns were examined with descriptive statistics, trend analysis, seasonal decomposition and time-series plots. Anomalous accounts were identified with four methods: the z-score, $z = (x_i - \mu)/\sigma$, which flags values far from the mean; the interquartile range (IQR) rule; DBSCAN; and the Isolation Forest. The results were compared across methods and combined into a consensus measure, and anomalies were visualised with t-distributed stochastic neighbour embedding (t-SNE; van der Maaten & Hinton, 2008). Accounts were then classified with k-means clustering, which minimises the within-cluster sum of squares, $\sum_i \sum_{x \in S_i} \|x - \mu_i\|^2$, over the k clusters $S_1, \ldots, S_k$. The number of clusters was chosen with the elbow method and checked against hierarchical clustering and principal component analysis (PCA). The analysis was carried out in R (ggplot2, forecast, cluster, factoextra) and Python (scikit-learn, PyOD).

4. Results

4.1 Data overview

Table 1 summarises the transactions. On average, residents made 1,528 transactions a month, worth ₦4.96 million. Tariff class 2 dominates, with 129,127 transactions (93.4%), followed by tariff 3 with 8,286 (6.0%); tariffs 4 (649) and 1 (248) are rarely used (Table 2).

Table 1: Summary of electricity transactions, 2012–2023

Metric	Value
Total transactions	138,310
Total amount (₦)	449,005,481.91
Average transactions per month	1,528.37
Average amount per month (₦)	4,957,105.29

Table 2: Transactions by tariff class

Tariff class	Transactions	Share (%)
2	129,127	93.4
3	8,286	6.0
4	649	0.5
1	248	0.2

4.2 Temporal patterns

Monthly transaction values rise steadily over the period, from about ₦1 million to ₦3 million a month in the early years to mostly between ₦4 million and ₦7 million a month in 2022 and 2023, with a peak above ₦9 million (Figure 1). Periodic fluctuations around the trend point to seasonal variation in consumption.

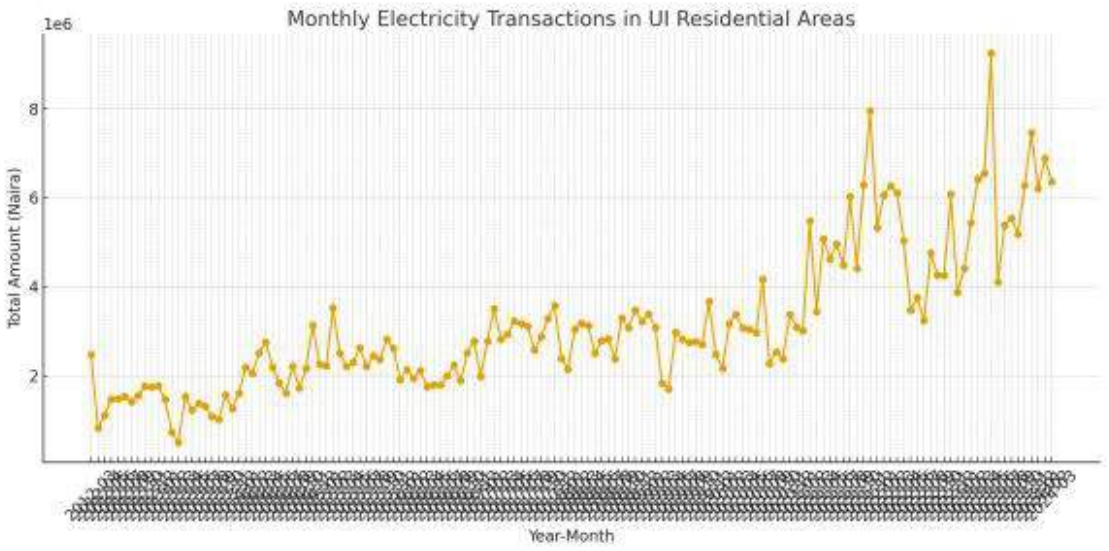


Figure 1: Monthly value of electricity transactions in UI residential areas, 2012–2023 (₦)

4.3 Anomaly detection

The methods differ markedly in how many accounts they flag (Table 3). The Isolation Forest is the most conservative, flagging 43 of the 1,411 accounts (3.0%). The z-score flags 211 accounts (14.95%) and DBSCAN 240 (17.01%), while the IQR rule is the most sensitive, flagging 493 (34.93%). Under the study's consensus rule, 312 accounts (22.11%) are potentially anomalous. In the t-SNE projection (Figure 2), anomalous accounts are scattered across the embedded space rather than forming a single group, but they sit apart from the dense groups of normal accounts. Such anomalies may reflect meter tampering, faulty meters or bypassing, all of which matter for revenue assurance.

Table 3: Accounts flagged as anomalous, by method

Method	Accounts flagged	Share of accounts (%)
Isolation Forest	43	3.05
Z-score	211	14.95
DBSCAN	240	17.01
Interquartile range (IQR)	493	34.93
Consensus	312	22.11

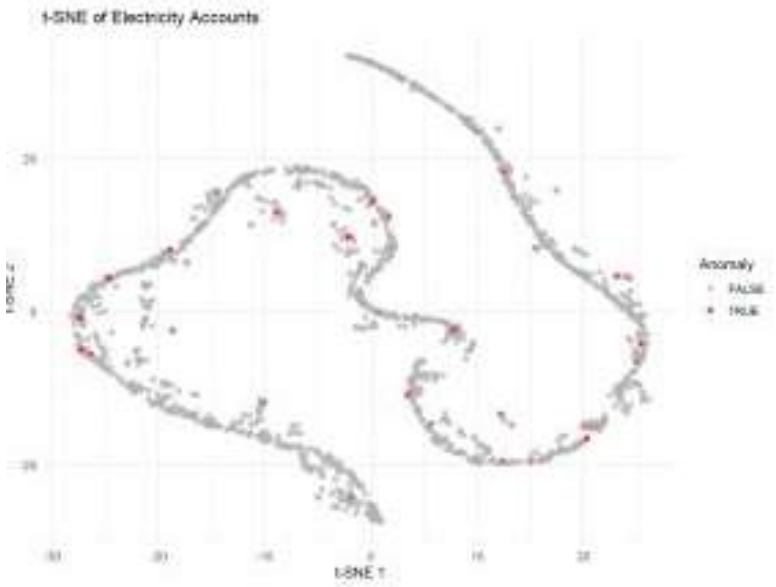


Figure 2: t-SNE projection of electricity accounts, with anomalous accounts highlighted

4.4 Consumption clusters

K-means clustering separates three consumption groups (Table 4). Cluster 1 contains 90 accounts (6.4%) with high and highly variable consumption; Cluster 2 contains 224 accounts (15.9%) with moderate consumption; and Cluster 3, the largest, contains 1,097 accounts (77.7%) with low, stable consumption. The elbow method supports three clusters, the hierarchical dendrogram shows the same three-group structure, and the first two principal components explain 57.3% of the variance (38.3% and 19.0%) (Figure 3). Cluster 1 is markedly higher on average, minimum and total consumption and on the variability of consumption, while Cluster 3 accounts make the most transactions (Figure 4). Cluster 1 therefore departs most clearly from standard residential behaviour.

Table 4: Electricity consumption clusters

Cluster	Accounts	Share (%)
1: High consumption, high variability	90	6.4
2: Moderate consumption	224	15.9
3: Low, stable consumption	1,097	77.7
Total	1,411	100.0

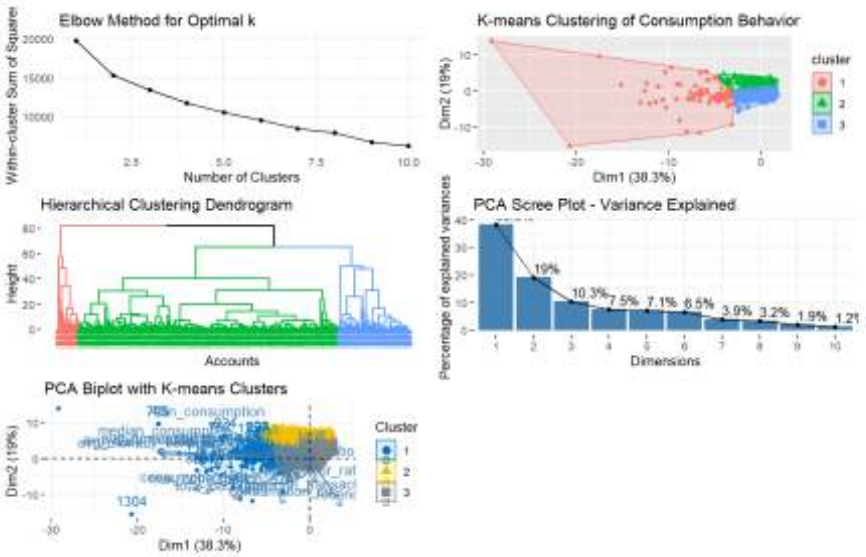


Figure 3: Cluster validation: elbow method, k-means clusters, hierarchical dendrogram, PCA scree plot and biplot

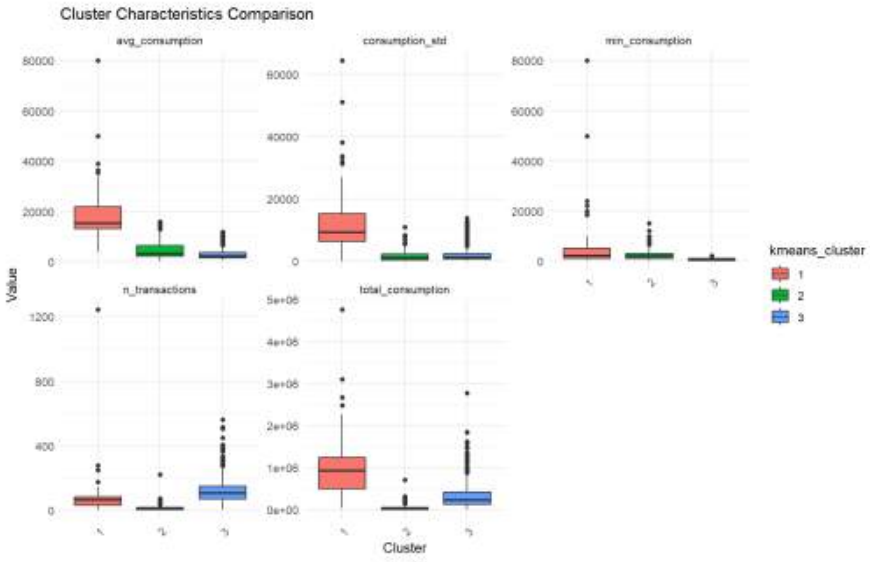


Figure 4: Consumption features by cluster

5. Discussion and Policy Implications

Three findings stand out. First, consumption has grown steadily and shows seasonal patterns that can support load forecasting. Second, depending on the method, between 3% and 35% of accounts behave unusually; this wide range shows that single-method screening is unreliable, and that results from several methods should be combined before accounts are investigated. Third, a small high-consumption group (Cluster 1, 90 accounts) shows the most extreme behaviour and is the natural starting point for audits.

Five measures follow: targeted audits of the 312 flagged accounts, starting with Cluster 1; cluster-based communication and demand-side management; a real-time monitoring dashboard so that anomalies are detected promptly; richer data, such as finer timestamps and geolocation; and the use of the clusters in load forecasting and maintenance planning.

6. Conclusion

The study shows that routinely collected prepaid-meter data, analysed with statistical and machine-learning methods, can reveal consumption trends, flag unusual accounts and segment customers in an institutional residential setting. The approach offers a practical framework for revenue assurance, operational efficiency and data-driven energy governance at the University of Ibadan, and for electricity utilities in Nigeria more widely. The anomalies identified are statistical signals rather than proof of wrongdoing, and they should be confirmed by field inspection.

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