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Stochastic Modeling of Key Macroeconomic Variables in Nigeria

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ABSTRACT:

The macroeconomic models in Nigeria had struggled understanding the dynamic, complex, and non-linear behaviours of macroeconomic variables, leading to gap in fully addressing the impact of shocks, monetary and fiscal policies in the country. This has heightened macroeconomic instability and led to low economic growth experienced over decades. This study applied stochastic modeling approach to understand the behaviour of key macroeconomic variables, make predictions and forecast, consider causal and feedback mechanism within the components of macroeconomic ecosystem. The results reveal that the approach provides better insight into addressing economic fluctuations by identifying the major drivers and formulate more effective policy response. The investigation suggests a favourable scenario where the Nigerian economy shift away from import dependency, improve domestic production, and creates an environment conducive to business and foreign direct investment. This will effectively contribute to stabilising the economy.

Key word: Stochastic modeling, shocks, scenario, simulation, Feedback, Macroeconomic variables

Introduction

Microeconomic variables in Nigeria like many other African countries are highly volatile and complex [1]. They are very important instrument for economic stability and growth. However, there are several approaches for modeling macroeconomic variables, one of the common features of these models is to help policy makers understand the behaviour of economic variables with the aimed of effective policy for economic prosperity. Macroeconomic models over the years had failed to fully addresses gaps in forecasting, prediction. thereby affecting policy interventions in Nigeria mostly dual to "omission of structures of the system being modeled and non-flexibility for scenario modeling" [2].

The Nigerian economy is among the largest on the African continent and depend heavily on the export of crude oil [3,4]. However, despite its abundance of natural resources, the economy has experienced challenges such as low growth, high inflation, fluctuations in the value of the naira, and high unemployment in recent years [5]. Macro-economic variables in Nigeria are complex, non-linear and highly volatile, Inflation rate in Nigeria continue to rise, stands at 33.20 % according to NBS. Exchange rate fluctuation is recorded on daily basis, that defile government policy intervention. Unemployment rate according to new Nigeria figures stands at 7.7 %, interest rate fluctuation above 26.7 %, economic growth statistics remain volatiles with decline witness over some period.

Nigeria, with its diverse and dynamic economic landscape, requires a more comprehensive macroeconomic model that delves into the interwoven dynamics of key economic indicators. This research aims simulate macroeconomic for the Nigerian economy using stochastics modelling approach. The model will be designed to capture the underlying information feedback structure/bahaviours (causal relationship, nonlinear structure, volatility and complexity) of key macro-economic variables, such as Gross Domestic Product (GDP), interest rates, exchange rates, unemployment rates, and inflation rates. The ultimate goal is to provide policymakers with invaluable insights for evaluation and shaping effective economic policies. As an oil-based economy, the fluctuations in oil prices and production alterations have significantly contributed to the vulnerabilities of Nigeria's economic and business climate. These shocks and symmetric fluctuations have significant impacts on businesses, economic growth, and macroeconomic variables [6]. Therefore, there is a pressing need to gain a better understanding of how the economy behaves in the face of economic uncertainty, external shocks, and randomness.

The model will also incorporate causal and feedback mechanism to capture the interactions between these variables. The insight gained from this research will provides a better understanding of the Nigerian economy under conditions of uncertainties, volatility, randomness and complexity. This will help informed research-based policy decisions aimed at promoting economic growth and maintain stability in Nigeria. According to [7], he stated that *"An economic system is an extremely complex system and needs to be understood before it is managed. Many economic theories only focus on a partial view of the economic system and dismiss other parts of the system and therefore miss their feedbacks into the economy. It is therefore fundamental to have a*

holistic understanding of a system in order to capture its Behaviour." The stochastic modeling of the Nigeria economy using system dynamics simulations approach is a veritable tool for policymakers and researchers seeking to understand the complex interactions between the various macroeconomic variables and the potential impact of different policies on the economic systems including their interaction and future impact. While admitting that there may be challenges and limitations using these approaches, continues research and development of robust model can help policymakers make more informed decisions and promote sustainable economic growth.

Literatures review

Stochastic modeling has been widely used in the literature to study the behaviour of volatile and shocks, and complex system. In the context of macroeconomic modeling, this approach is becoming increasingly engaged to capture volatility, complexity, non-linearity interaction that are inherent in economic systems [8]

Economic system are dynamics, complex, non-linear and compresses of many interacting agents. To effectively manage an economy, a deep understanding is essential. Many economic theories tend to adopt a narrow perspective, concentrating on specific aspects while overlooking the broader systemic interactions. This oversight can have profound implications, as it often results in the failure to account for critical causal structure and their consequences within the economy. Therefore, it is imperative to cultivate a holistic understanding of the entire economic system to accurately capture its dynamic behaviour and make informed policy decisions [9].

Studies have demonstrated the effectiveness of stochastic analysis in macroeconomic modeling. [10] developed a macroeconomic model which study the component of the feedback between structure and behaviours. Ding and Vo, used the multivariate stochastic volatility (MSV) and multivariate GARCH (MGARCH) models to investigate the volatility interactions between the oil market and the foreign exchange (FX) market, in an attempt to extract information intertwined in the two for better volatility forecast [11]. [12] examines the dynamic properties of output and inflation fluctuations that occur in response to economic shocks. They use a dynamic approach and constructs two system dynamic models to examine the dynamics of output, prices, wage and inflation. Policymakers need to paid close attention to. High inflationary rate can lead to decreased in purchasing power, external debt, fiscal deficit, exchange rates, increased interest rates, and reduced investment [13,14]. It was also used to model forecasting of crude oil reserve and production capacity in Nigeria by [2]

The stochastics modeling methodology is widely applied for analysis system volatility of and random system shocks [15,16]. In the Nigerian economic literatures, stochastic modeling had been used to simulate the behaviour of various macroeconomic variables, including GDP, inflation, interest rate, exchange rate, and unemployment, in order to inform policy decisions [17]. Sovilj *et al*, assert that stochastic general equilibrium (DSGE) performed poorly in modelling and explaining real world phenomena especially related to the latest (2007-2009) global financial crisis [9]. Stochastics modeling provides an important tool for better understanding economic variables and their analysing complex economic system by incorporating randomness and probability distribution into the model to better capture behaviors of economic variables and their interactions [18,19]. The application of stochastic modeling simulation can help researchers and policymakers better understand the potential outcomes of different economic policy under different scenarios and identify effective policy interventions [20].

Economic variables are highly interrelated, as posited by [21], there is a dynamic relationship among macroeconomic variables and economic growth in Nigeria. The economy is complex and without causal and structural insight it become difficult to understand and formulate sustainable economic policies. To promote sustainable economic growth, it is crucial to develop effective approaches(model) for comprehending the complexity of this volatility [22]. Policymakers, investors, and other stakeholders (including academia) have to understand the behaviour of the economy in the face of uncertainty and random shocks in order make informed decisions [23]. The high volatility, complex and nonlinearity of macroeconomic variables in Nigeria calls for a paradigm and new approach to policy design and methodology.

Methodology

The study employed causal research design, and stochastic modeling approach to conduct simulation studies on macroeconomic variables. It used historical data from 1981 to 2023 on GDP, Exchange Rate (EXR), Interest rate (IR), Inflation rate (IFL), and Unemployment rate (UEMPL) as the key macroeconomic variables. Other variables in include Investment (INV), Import (IMP), Export (EXP), and Foreign Direct Investment (FDI). The study utilized Vector Autoregressive model to capture the dynamic interdependency among the study variables.

Mode specification

$$\frac{dx}{dt} = \mu(X(t), t) + \sigma(X(t), t).\eta_t$$

η_{t1} and η_{t2} are at least significant where $t_1 \neq t_2$

η_t is stationary

$\mathbb{E}(\eta_t) = 0$ for all t

Vector Autoregressive (VAR) Model Specification

VAR is use to determine the interrelationship among variables in the system

$GDP = GDP_t$

$Exchange\ rate = EXR_t$

$Unemployment\ rate = UNEMP_t$

$Interest\ rate = IR_t$

$Infaltion = IFL_t$

$X_t = \alpha + \sum_{i=1}^{p} A_i\, x_{t-1} + \varepsilon_t$

$X_t = A_1 X_{t-1} + A_2 X_{t-2} + \cdots + A_p X_{t-p} + \varepsilon_t$, where

$$X_t = \begin{pmatrix} GDP_t \\ EXR_t \\ UNEMP_t \\ IR_t \\ IFL_t \end{pmatrix} is\ the\ vector\ of\ the\ variables$$

$A_1, A_2, \ldots, A_3$ are the matrix of the coefficient that will be estimated

$$\boldsymbol{\epsilon_t} = \begin{pmatrix} \epsilon_{GDP} \\ \epsilon_{EXR} \\ \epsilon_{UNEMP} \\ \epsilon_{IR} \\ \epsilon_{IFL} \end{pmatrix} is\ the\ vector\ of\ the\ error\ terms\ that\ are\ assume\ to\ be\ white\ noise$$

$GDP_i = a_{11}GDP_{t-1} + a_{12}EXR_{t-2} + a_{13}UNEMP_{t-3} + a_{14}IR_{t-4} + a_{15}IFR_{t-5} + \varepsilon_{GDP_i}$

$EXR_i = a_{21}GDP_{t-1} + a_{22}EXR_{t-2} + a_{23}UNEMP_{t-3} + a_{24}IR_{t-4} + a_{25}IFR_{t-5} + \varepsilon_{EXR_i}$

$UNEMP_i = a_{31}GDP_{t-1} + a_{32}EXR_{t-2} + a_{33}UNEMP_{t-3} + a_{34}IR_{t-4} + a_{35}IFR_{t-5} + \varepsilon_{UNEMP_i}$

$IR_i = a_{41}GDP_{t-1} + a_{42}EXR_{t-2} + a_{43}UNEMP_{t-3} + a_{44}IR_{t-4} + a_{45}IFR_{t-5} + \varepsilon_{IR_i}$

$IFR_i = a_{51}GDP_{t-1} + a_{52}EXR_{t-2} + a_{53}UNEMP_{t-3} + a_{54}IR_{t-4} + a_{55}IFR_{t-5} + \varepsilon$

$where\ a_{ij}$ are the coefficient estimate

Data Description

The data untilised in this analysis were sourced from reputable institutions. data utilized in this, including the Central Bank of Nigeria (CBN), the National Bureau of Statistics (NBS), and the World Bank Database. The dataset comprises annual measurements of key economic indicators, reported in the local currency. To analyze the data, the researchers employed the R statistical software, specifically using the RStudio environment. This software was chosen for its robust statistical and econometric capabilities, allowing for comprehensive modeling and analysis.

Results and Discussions

The research examined the dynamic interactions between GDP, inflation, interest rates, unemployment, and exchange rates. By simulating the model with various stochastic elements and policy interventions, we assess how these variables influence each other over time.

Table 1: Summary Statistics from the data

	GDP	INFLATION	INTEREST_RATE	EXR	UNEMPLOYMENT
Mean	3.056512	5.129759	17.35721	3.731379	3.162884
Median	3.460000	5.614123	16.94000	4.775504	3.791000
Maximum	15.33000	12.16099	31.65000	6.789411	5.633000
Minimum	-13.13000	0.498918	8.920000	-0.494296	0.000000
Std. Dev.	5.256186	2.656281	4.763771	2.048385	1.827877
Skewness	-0.846830	0.264254	0.340300	-0.783252	-0.991749
Kurtosis	4.853653	2.840759	3.662494	2.460712	2.450552

Jarque-Bera	11.29559	0.545883	1.616291	4.917708	7.589778
Probability	0.003525	0.761137	0.445684	0.085533	0.022485
Sum	131.4300	220.5796	746.3600	160.4493	136.0040
Sum Sq. Dev.	1160.355	296.3449	953.1275	176.2270	140.3277

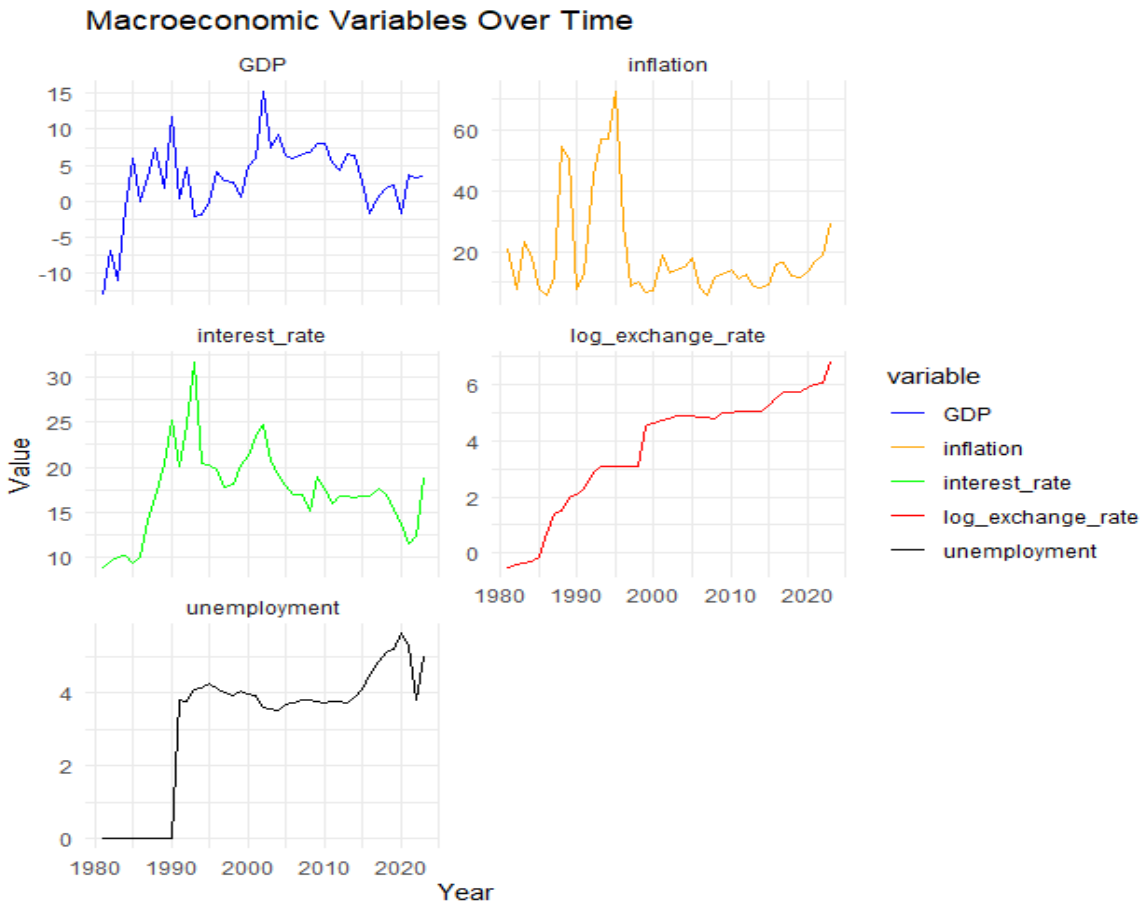

Figure 1: Time Plot of Macroeconomic Variables

The graph shows the trends of key macroeconomic variables in Nigeria from 1981 to 2023, It illustrates the dynamic and volatile nature of Nigeria's key macroeconomic variables: GDP, inflation, interest rate, exchange rate, and unemployment, each exhibiting significant fluctuations and trends. The data shows high volatility and uncertainty across all macroeconomic variables. These variables are likely interdependent. capture the dynamic interactions between these macroeconomic indicators. The trends reflect significant impacts of policy decisions on interest rates and inflation. Incorporating policy response functions within the stochastic models to improve their predictive power and realism

VAR Model Estimation for GDP, Exchange Rate, Interest Rate, Inflation and Unemployment

To understanding the dynamic relationship of the endogenous data. The table below presents the estimation results from a Vector Autoregression (VAR) model applied to five endogenous variables: Gross Domestic Product (GDP), exchange rate, interest rate, inflation, and unemployment. The results include coefficients, standard errors, t-values, and p-values for each lagged variable in the system, providing insights into the dynamic interrelationships among the variables.

Table 2: VAR Model Estimation for GDP, Exchange Rate, Interest Rate, Inflation and Unemployment

==========

$$GDP = 0.348GDP_{t-1} + 1.129EXR_{t-1} + 0.04IR_{t-1} + 0.025IFL_{t-1} - 1.024UNEMPL_{t-1} - 0.349$$

	Estimate	Std. Error	t-value	Pr(>|t|)
GDP	0.3483	0.1729	2.014	0.0515
Exchange e rate	1.12965	0.8017	1.617	0.1146

Interest rate	0.0405	0.1825	0.222	0.8225
Inflation	0.0253	0.0461	0.550	0.5856
Unemployment	-1.0246	0.8245	-1.243	0.2220
Const	-0.3495	2.6848	-0.130	0.8971

$Signif.codes$: 0 ‘$***$’ 0.001 ‘$**$’ 0.01 ‘$*$’ 0.05 ‘.’ 0.1 ‘ ’ 1

$Residual\ standard\ error$: 3.928 on 36 $degrees\ of\ freedom$

$Multiple\ R-Squared$: 0.3772, $Adjusted\ R-squared$: 0.2908

$F-statistic$: 4.362 on 5 and 36 $DF,\quad p-value$: 0.003317

Estimation results for equation log_exchange_rate:

==========

$$EXR = 0.019GDP_{t-1} + 0.891EXR_{t-1} - 0.016IR_{t-1} - 0.001IFL_{t-1} + 0.073UNEMPL_{t-1} + 0.603$$

	Estimate	Std. Error	t- value	Pr(>|t|)
GDP	0.0194	0.0125	1.544	0.1329
Exchange e rate	0.8911	0.0581	15.315	< 2e-16***
Interest rate	-0.0168	0.0132	-1.271	0.2118
Inflation	-0.0014	0.0033	-0.445	0.6579
Unemployment	0.0734	0.0598	1.228	0.2273
Const	0.6037	0.1948	3.099	0.0037**

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2851 on 36 degrees of freedom

Multiple R-Squared: 0.9815, Adjusted R-squared: 0.9789

F-statistic: 381.5 on 5 and 36 DF, p-value: < 2.2e-16

Estimation results for equation interest_rate:

==========

$$IR = 0.114GDP_{t-1} + 0.037EXR_{t-1} + 0.651IR_{t-1} + 0.041IFL_{t-1} - 1.074UNEMPL_{t-1} + 5.225$$

	Estimate	Std. Error	T value	Pr(>|t|)
GDP	0.1143	0.1316	0.868	0.3911
Exchange e rate	0.0372	0.6102	0.061	0.9516
Interest rate	0.6516	0.1389	4.691	3.85e-06***
Inflation	0.0417	0.0350	1.191	0.2414
Unemployment	-0.0746	0.6275	-0.119	0.9060
Const	5.2251	2.0436	2.557	0.0149*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.99 on 36 degrees of freedom

Multiple R-Squared: 0.6343, Adjusted R-squared: 0.5836

F-statistic: 12.49 on 5 and 36 DF, p-value: 4.586e-07

Estimation results for equation inflation:

==========

$$Infl = -0.053GDP_{t-1} - 2.388EXR_{t-1} + 0.539IR_{t-1} + 0.500IFL_{t-1} + 1.774UNEMPL_{t-1} + 3.686$$

	Estimate	Std. Error	T value	Pr(>|t|)
GDP	-0.0533	0.5985	-0.089	0.9286
Exchange e rate	-2.3884	2.7747	-0.861	0.3951
Interest rate	0.5391	0.6316	0.854	0.3990
Inflation	0.5002	0.1595	3.136	0.0034**
Unemployment	1.7749	2.8534	0.622	0.5378
Const	3.6861	9.2917	0.397	0.6939

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 13.6 on 36 degrees of freedom

Multiple R-Squared: 0.4057, Adjusted R-squared: 0.3231

F-statistic: 4.915 on 5 and 36 DF, p-value: 0.001573

Estimation results for equation unemployment:

==========

$$Unemp = -0.017GDP_{t-1} + 0.185EXR_{t-1} + 0.081IR_{t-1} - 0.011IFL_{t-1} + 1.65UNEMPL_{t-1} - 0.6405$$

	Estimate	Std. Error	T value	Pr(>|t|)
GDP	-0.0171	0.0257	-0.664	0.5109
Exchange e rate	0.1856	0.1195	1.553	0.1292
Interest rate	0.0818	0.0272	3.007	0.0047
Inflation	-0.0111	0.0068	-1.619	0.1141
Unemployment	0.6554	0.1229	5.330	0.0005
Const	-0.6405	0.4003	-1.600	0.1184

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5858 on 36 degrees of freedom

Multiple R-Squared: 0.905, Adjusted R-squared: 0.8918

F-statistic: 68.6 on 5 and 36 DF, p-value: < 2.2e-16

The vector autoregression (VAR) estimation results suggest the following insights across the five endogenous variables (GDP, exchange rate, interest rate, inflation, unemployment) with a constant term included. Each equation's coefficients reveal varied impacts: for GDP, only the lagged GDP and exchange rate show marginal significance ($p = 0.0515$ and $p = 0.1146$, respectively). Exchange rate is highly significant ($p < 2e\text{-}16$), with strong explanatory power (Adjusted R-squared: 0.9789). Interest rate's equation shows significance for its own lag ($p < 0.0001$) and moderate overall explanatory power (Adjusted R-squared: 0.5836). Inflation's equation indicates significance for its own lag ($p = 0.0034$) but relatively lower overall explanatory power (Adjusted R-squared: 0.3231). Unemployment exhibits significant effects from its own lag ($p < 0.00001$) with high explanatory power (Adjusted R-squared: 0.8918). Residual diagnostics show varying residual standard errors across equations, with correlations revealing interdependencies between GDP and unemployment, and weaker relationships elsewhere. Overall, the VAR model highlights complex dynamics among the variables, with varying levels of economic impact and mutual relationships.

Within-Sample Performance

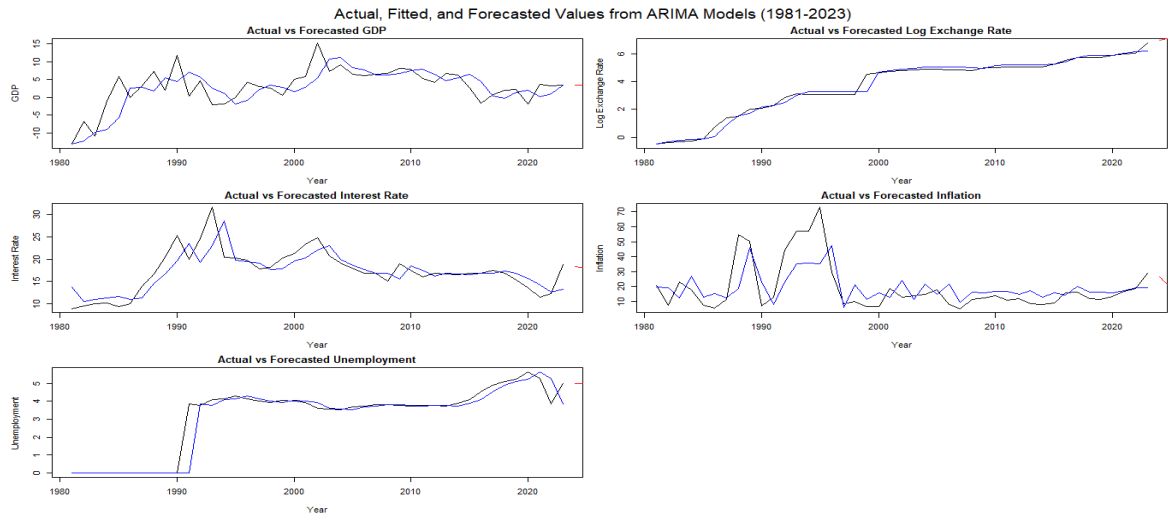

Figure 2: Actual vs forecasted values

Time series data running from 1981 to 2023 is used to generate a static solution for the model. The actual values are plotted against the simulation values for the endogenous variables in Figure 3. The figure shows that the predicted series are very close to actual series except for inflation and GDP and inflation which has few gaps between actual and predicted series. However, the closeness of the predicted series to the actual series indicates a good forecasting power of the model thus, suggesting that the simulation result will be valid for policy prescriptions

Sensitivity Analysis to Assess how Changes in Model Parameters Affect Key Variables

The research explored policy scenarios that involved the five macroeconomic variables of the study and the joint scenarios of the model that looked into the dynamic characteristics of inflation, unemployment, interest rate, exchange rate and Gross Domestics Product structure to national growth. Utilizing stochastic dynamics give room for modeling scenarios to solve macroeconomic problems and provide choices to make informed decisions.

Different Scenario Analysis

Scenerio1: 10 % depreciation in Exchange rate

Scenario 2: 10 % decrease in export in of oil and non-oil materials

Scenario 3: 10 % decrease in import

Scenario 4: 10 % increase in foreign direct investment

Scenario 5: Floating the naira

Table 3: Policy Scenarios

Variables	Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
GDP	2024	6.14	6.57	8.28	5.37	6.03
	2025	7.46	8.35	9.38	6.59	7.13
	2026	8.07	9.02	8.84	6.57	8.12
Exchange rate	2024	7.71	6.99	6.81	6.88	10.72
	2025	7.83	7.09	6.80	6.91	11.10
	2026	7.87	7.12	6.77	6.92	11.35
Interest rate	2024	20.51	21.24	21.40	19.27	21.60
	2025	21.65	23.04	22.74	19.89	23.91
	2026	22.06	23.79	22.78	19.71	25.67
Inflation	2024	33.58	38.69	32.16	28.40	39.03
	2025	31.75	39.05	27.98	23.84	43.19
	2026	27.46	34.95	22.48	18.87	45.18

Unemployment	2024	5.15	4.77	4.98	5.07	5.27
	2025	5.46	4.78	5.20	5.26	5.81
	2026	5.79	4.99	5.57	5.466	6.38

Discussion

In the five scenarios for the Nigerian economic, show the impact of policy decision on the economic through change of the parameter. In Scenario 1, a 10% depreciation in exchange rate led to higher interest rate and unemployment. Scenario 2, with a 10% decrease in export, shows impact on GDP, rising interest rate and stable unemployment. Scenario 3, a 10 % decrease in import result to strong GDP growth, stable exchange rate, and decreasing inflation. Scenario 4, with a 10 % increase in FDI, leads to slight GDP growth, stable exchange rates, lower interest rate and unemployment. Finally, scenario 5, floating the naira, shows modest GDP growth but significant volatility in exchange rates, high inflation, and rising unemployment

Conclusion

The application of stochastics methodology enhanced the understanding, prediction and accuracy of macroeconomic studies. This approach serves as a valuable tool for policy makers aiming to understand the intricate interactions among macroeconomic variables and assess the potential impact of different policies on economic ecosystem, including their causal and feedback mechanism [24].

The finding from the simulation result highlights the importance of reducing import and increasing domestic and foreign direct investment to improve macroeconomic stability in Nigeria. Reviving and protecting the manufacturing is crucial to achieve favourable balanced of trade and ensuring self-sufficiency. Reduced import scenario is effective in the enhancement of exchange rate, GDP, employment and decrease in interest rate, ultimately stabilizing the economy [23]. By shifting focus towards boosting domestic production and creating a conducive business environment to attract investment, Nigeria can move from import dependency, stimulate growth, and foster economic stability.

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