



Dynamics of Inflation, Interest and Exchange Rates with the Effects of Money Supply and GDP in Nigeria: Evidence from BVARX Models

M. O. Adenomon^{a,b,c,*} and H. K. Oduwole^d

^a Department of Statistics, NSUK-LISA Stat Lab, Nasarawa State University, Keffi, Nigeria.

^b International Association of Statistical Computing (IASC) African Members Group, Nigeria.

^c Foundation of Laboratory for Econometrics and Applied Statistics of Nigeria (FOUND-LEAS-IN-NIGERIA), Nigeria.

^d Department of Mathematics, Nasarawa State University, Keffi, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

Economic theory revealed evidence of interrelationships among inflation, interest and exchange rates. Such theory further states possible effects of money supply and GDP on inflation, interest and exchange rates. This study focuses on the dynamic interrelationships among inflation, interest and exchange rates with the effects of money supply and GDP in Nigeria using Bayesian Vector Autoregression with Exogenous variables (BVARX) models. To achieve this, data was sourced from the Central bank of Nigeria (CBN) website spanning the period of 2010Q1-2020Q4. The study proposed six (6) versions of BVARX models with lag 2 using Normal-Wishart, Normal Flat and Flat-Flat priors. The results revealed superior BVARX models with Flat-Flat prior using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) as means of model selection. Lastly, evidence from Bivariate Granger causality testing reveals that the past lag values of inflation rate help in predicting exchange rate in Nigeria.

Keywords: Inflation; interest; exchange; BVARX; priors; RMSE; MAE.

[°]Chair;

*Corresponding author: Email: adenomonmo@nsuk.edu.ng;

1 Introduction

Macroeconomic variables such as inflation, interest and exchange rates are very important to policy makers. This is so because these variables can affect money supply, foreign exchange and, goods and services (output) of any economy such as Nigeria [1]. Economic theory revealed evidence of interrelationships among inflation, interest and exchange rates for example in Turkey [2] in Nigeria [1]. Such theory further states possible effects of money supply and GDP on inflation, interest and exchange rates. In this case from Vector Autoregression (VAR) methodology, inflation, interest and exchange rates are endogenous variables while money supply and GDP are exogenous variables.

VAR methodology superficially resembles simultaneous equation modelling in that we consider several endogenous variables together. In which each endogenous variable is explained by its lagged values and the lagged values of all the other endogenous variable in the model [3], Gujarati [4]. The VAR model may either include exogenous variable or not. But some time series modelers believe that including exogenous variables to VAR (VARX) model, forecast can be improved. Is on this background that this study implemented the Bayesian VAR with exogenous variables (BVARX) model.

Recent studies in econometrics have identified the superiority of Bayesian VAR with exogenous variables (BVARX) over Bayesian VAR and standard VAR models in terms of in-sample and out-sample forecasts [5]. The reason is because potential exogenous variables could improve the performance of BVAR models [6]. While application of BVARX in forecasting cryptocurrencies can be seen in Bohte and Rossini [7].

This study focuses on the dynamic interrelationships among inflation, interest and exchange rates with the effects of money supply and GDP in Nigeria using Bayesian Vector Autoregression with Exogenous variables (BVARX) models.

2 Brief Literature on the Dynamic Interrelationships among Inflation, Interest and Exchange Rates with the Effects of Money Supply and GDP in Nigeria and Other Economy

Economic theory revealed evidence of interrelationships among inflation, interest and exchange rates. Such theory further states possible effects of money supply and GDP on inflation, interest and exchange rates.

Bello and Saulawa [8] investigated the relationship between money supply, interest rate, income growth and inflation rate in Nigeria from 1980 to 2010. The study implemented cointegration test, VAR model and granger causality test. The study revealed that money supply, interest and income generation all granger cause inflation rate in Nigeria.

Ebiringa and Anyaogu [9] investigated the interrelationship between exchange rate, inflation and interest rates using historical data from 1971 to 2010 applying the ARDL model. The study revealed a significant short-run and long run positive relationship between inflation and exchange rate while interest rate had negative relationship but not significant.

He [10] in another economy examined the relationship between money supply and the macroeconomic variables (real GDP, Inflation rate and the interest rate) in China using VAR model. The study concluded that increase in GDP and inflation can lead to increase in money supply while increase in interest rate lead to decrease in money supply.

Laksono [11] determined the effect of the money supply, interest rate, government spending and the real exchange rate on the inflation rate in Indonesia using Vector Error Correction Model (VECM). The study indicated that all independent variables had a significant short-run and long-run equilibrium relationship to the dependent variable. But money supply and inflation rate was negatively related.

Okuneye and Sangosanya [12] investigated the growth effects of interest, inflation and exchange rates in Nigeria using annual data from 1999 to 2017 with the application of cointegration test and granger causality test. The result

suggested a uni-directional causal relationship between inflation, exchange and economic growth in Nigeria with evidence of long run relationships. Similar evidences are presented in Osuala et al. [13] and Umaru and Zubairu [14].

Wauk and Ajorlolo [15] investigated the games of monetary policy, inflation and economic growth of the Ghanaian economy for the period of 1982 to 2017 using ARDL to cointegration model. The study revealed a significant negative relationship between interest rate and economic growth, and insignificant relationship between economic growth and exchange rate. In Nigeria, Anowor and Okorie [16] found that there is a significant influence of monetary policy on Nigeria economy.

Henry and Sabo [17] examined the impact of monetary policy management on inflation during 1985 to 2019 using ARDL model. The study concluded that monetary policy rate and foreign rate impacted negatively on inflation while broad money supply impacted positively on inflation in Nigeria.

Ozen et al. [2] measured the effects of changes in exchange rates and interest rates on inflation, to determine which of the exchange rates and interest rates has greater Impact on inflation rates following the July 15, 2016 coup attempt in Turkey. The study implemented the cointegration test, Fully Modified OLS and granger causality test. The study reported long run relationship between inflation rate, exchange rate and interest rate while the fully modified OLS revealed that the effect of the USD exchange rate on inflation is more than that of bank loan interest rate in Turkey.

Babalola et al. [18] determine the effect of inflation and interest on economic growth in Nigeria from the period of 1981 to 2014 using Ordinary Least Square (OLS) method. The result indicated a negative effect of inflation and interest rates on economic growth in Nigeria.

Olayungbo and Ajuwon [19] investigated the relationship among dollarization, inflation and interest in Nigeria for the period of 1986 to 2015 Q1 using structural vector Autoregression (SVAR) model. The study shown that dollarization index has been on the increase since 1994 despite stable and low inflation and interest rate.

Most of the previous work employed VAR, ARDL model, VECM model to empirical study, but our present work employed Bayesian VAR model with exogenous variables with the intension to improve forecast when compared to VAR and BVAR.

3 Methodology, Model Description and Specifications

3.1 Methodology

This study employed quarterly data on inflation, interest and exchange rates, money supply and GDP in Nigeria which was sourced from the Central bank of Nigeria (CBN) website spanning the period of 2010Q1-2020Q4. The training data set covers the period of 2010Q1-2018Q4 while the validation/testing data set covers the period of 2019Q1-2020Q4.

3.2 Model description and specifications

3.2.1 Bayesian Vector Autoregression with Sims-Zha prior and BVARX model

The BVAR model of Sims and Zha [20] has gained popularity both in economic time series and political analysis, because the Sims-Zha BVAR allows for a more general specification and can produce a tractable multivariate normal posterior distribution, which leads to robust estimation and estimates. Again, the Sims-Zha BVAR estimates the parameters for the full system in a multivariate regression [21].

In the reduced form model in (1) below:

$$y_t = c + y_{t-1}B_1 + \dots + y_{t-p}B_p + u_t \tag{1}$$

where $c = dA_0^{-1}$, $B_l = -A_lA_0^{-1}$, $l = 1, 2, \dots, p$, $u_t = \varepsilon_tA_0^{-1}$ and $\Sigma = A_0^{-1}A_0^{-1}$

The matrix representation of the reduced form is given as

$$Y = \begin{matrix} X \\ T \times m \end{matrix} \begin{matrix} \beta \\ T \times (mp+1) \end{matrix} + \begin{matrix} U \\ (mp+1) \times m \end{matrix}, U \sim MVN(0, \Sigma) \tag{2}$$

We can then construct a reduced form Bayesian SUR with the Sims-Zha prior as follows. The prior means for the reduced form coefficients are that $B_1=I$ and $B_2, \dots, B_p=0$. This means that $B_1=I$, that is B_1 is an identity matrix while $B_2, \dots, B_p=0$, that is B_2, \dots, B_p are equal to null matrices. We assume that the prior has a conditional structure that is multivariate Normal-inverse Wishart distribution for the parameters in the model. To estimate the coefficients for the system of the reduced form model with the following estimators

$$\hat{\beta} = (\Psi^{-1} + X'X)^{-1}(\Psi^{-1}\bar{\beta} + X'Y) \tag{3}$$

$$\hat{\Sigma} = T^{-1}(Y'Y - \hat{\beta}'(X'X + \Psi^{-1})\hat{\beta} + \bar{\beta}'\Psi^{-1}\bar{\beta} + \bar{S}) \tag{4}$$

where the Normal-inverse Wishart prior for the coefficients is

$$\beta / \Sigma \sim N(\bar{\beta}, \Psi) \text{ and } \Sigma \sim IW(\bar{S}, \nu) \tag{5}$$

This representation translates the prior proposed by Sims and Zha form from the structural model to the reduced form (Brandt and Freeman [21,22]), and Sims and Zha [20,23].

The summary of the Sims-Zha prior is given in Table 1.

Table 1. Hyperparameters of Sims-Zha reference prior

Parameter	Range	Interpretation
λ_0	[0,1]	Overall scale of the error covariance matrix
λ_1	>0	Standard deviation around A_1 (persistence)
λ_2	=1	Weight of own lag versus other lags
λ_3	>0	Lag decay
λ_4	≥ 0	Scale of standard deviation of intercept
λ_5	≥ 0	Scale of standard deviation of exogenous variable coefficients
μ_5	≥ 0	Sum of coefficients/Cointegration (long-term trends)
μ_6	≥ 0	Initial observations/dummy observation (impacts of initial conditions)
ν	>0	Prior degrees of freedom

Source: Brandt and Freeman [21]

The Bayesian Vector Autoregressive Model with exogenous variable is known as the BVARX (p,s) model. BVARX simply refers to a BVAR-model with suitable lag restrictions on the exogenous variables of the model [24,25].

The form of the BVARX (p,s) model can be given as

$$y_t = \delta + \sum_{i=1}^p \phi_i y_{t-i} + \sum_{i=0}^s \Theta_i X_{t-i} + \varepsilon_t \tag{6}$$

Where y_t is the endogenous variables, y_{t-1} is lag of the endogenous variables, X_{t-1} lag of the exogenous variables, δ vector of constants, ϕ_i matrix of coefficients of the lag endogenous variables, Θ_i matrix of coefficients of the lag exogenous variables and ε_t is the error terms.

The parameter estimates can be obtained by representing the general form of the multivariate linear model

$$y = (X \otimes I_t)\beta + e \tag{7}$$

The prior means for the AR coefficients are the same as those of the BVAR(p). The prior means for the exogenous coefficients are set to zero.

3.2.2 The BVARX priors

This study employed the following priors: Normal-Inverse Wishart, Normal-Flat and Flat-Flat.

The Normal-inverse-Wishart Distribution (also known as Gaussian-inverse-Wishart distribution) is a multivariate four-parameter family of continuous probability distributions. It is the **conjugate prior of a multivariate normal distribution with unknown mean and covariance matrix** (the inverse of the precision matrix).

Given (μ, Σ) has a normal-inverse-Wishart distribution denoted as

$$(\mu, \Sigma) \sim NIW(\mu_0, \lambda, \Psi, \nu)$$

The probability density function (pdf) is given as

$f(\mu, \Sigma / \mu_0, \lambda, \Psi, \nu) = N(\mu / \mu_0, \frac{1}{\lambda} \Sigma) W^{-1}(\Sigma / \Psi, \nu)$ [26]. Here the mean is normal while the standard deviation follows inverse Wishart distribution.

For the Normal-Flat prior, the mean follows a normal distribution while the standard deviation follows a uniform distribution.

The Flat-Flat Prior have mean that follows a uniform distribution and standard deviation also follows a uniform distribution. Basically the flat prior is also known as non-informative prior which assigns equal likelihood on all possible values of the parameter. The Jeffreys' prior is a good example of non-informative prior (Jeffreys [27]).

3.2.3 Model specifications

The six (6) versions of Sims-Zha Bayesian VARX model given below

- BVARX1 = $(\lambda_0 = 0.6, \lambda_1 = 0.1, \lambda_3 = 1, \lambda_4 = 0.1, \lambda_5 = 0.07, \mu_5 = \mu_6 = 5)$
- BVARX2 = $(\lambda_0 = 0.8, \lambda_1 = 0.1, \lambda_3 = 1, \lambda_4 = 0.1, \lambda_5 = 0.07, \mu_5 = \mu_6 = 5)$
- BVARX3 = $(\lambda_0 = 0.6, \lambda_1 = 0.15, \lambda_3 = 1, \lambda_4 = 0.15, \lambda_5 = 0.07, \mu_5 = \mu_6 = 2)$
- BVARX4 = $(\lambda_0 = 0.8, \lambda_1 = 0.15, \lambda_3 = 1, \lambda_4 = 0.15, \lambda_5 = 0.07, \mu_5 = \mu_6 = 2)$
- BVARX5 = $(\lambda_0 = 0.9, \lambda_1 = 0.1, \lambda_3 = 1, \lambda_4 = 0.1, \lambda_5 = 0.07, \mu_5 = \mu_6 = 2)$
- BVARX6 = $(\lambda_0 = 0.9, \lambda_1 = 0.15, \lambda_3 = 1, \lambda_4 = 0.15, \lambda_5 = 0.07, \mu_5 = \mu_6 = 5)$

where $n\mu$ is prior degrees of freedom given as $m+1$ where m is the number of variables in the multiple time series data. In this work $n\mu$ is 4 (that is two (3) time series variables plus 1(one)).

3.2.4 Lag length selection in Bayesian vector autoregressive models

The optimal lag length (p) is usually determined using one of the following popular criteria and p is chosen to be the order that minimizes some criteria (that is p is shown with the least value of the criteria).

The criteria are Akaike Information Criterion (AIC); Schwarz Information Criterion (SIC); Hannan and Quinn information Criterion (HQIC) where

$$AIC_{(p)} = \ln|\hat{\Sigma}_{(p)}| + \frac{2}{T} pk^2 \tag{8}$$

$$SIC_{(p)} = \ln|\hat{\Sigma}_{(p)}| + \frac{\ln T}{T} pk^2 \tag{9}$$

$$HQIC_{(p)} = \ln|\hat{\Sigma}_{(p)}| + \frac{2 \ln \ln T}{T} pk^2 \tag{10}$$

and $\hat{\Sigma}$ = estimated covariance matrix, T= number of observations, p is the optimal lag length of the Bayesian VAR model, k is the number of the autoregressive parameters estimated in a Bayesian VAR(p) model [28].

3.2.5 The following are the criteria for Forecast assessments used:

1. Mean Absolute Error (MAE) has a formular $MAE_j = \frac{\sum_{i=1}^n |e_i|}{n}$. This criterion measures deviation from the series in absolute terms, and measures how much the forecast is biased. This measure is one of the most common ones used for analyzing the quality of different forecasts.
2. The Root Mean Square Error (RMSE) is given as $RMSE_j = \sqrt{\frac{\sum_{i=1}^n (y_i - y^f)^2}{n}}$ where y_i is the time series data and y^f is the forecast value of y [29].

For the two measures above, the smaller the value, the better the fit of the model [30].

4 Results and Discussion

The data used in study was analyzed using MSBVAR package in R [31]. Analysis was performed on the logarithm transformation of the macroeconomic variables. The descriptive statistics is presented in the Table 2 below.

Table 2. Descriptive statistics

	LNCPI	LNEXCH	LNGDP	LNINRT	LN2
Mean	5.102182	5.277226	16.58553	2.001873	17.76654
Median	5.068440	5.060215	16.59235	2.108160	17.79780
Maximum	5.607680	5.730370	16.76210	2.422590	18.17960
Minimum	4.647810	5.011070	16.34790	1.276280	17.28940
Std. Dev.	0.283707	0.296724	0.106762	0.279284	0.253302
Skewness	0.225174	0.714389	-0.337551	-1.395693	-0.220972
Kurtosis	1.942566	1.732861	2.402335	4.092974	2.081133
Jarque-Bera	1.981471	5.470573	1.219448	13.47964	1.559445
Probability	0.371304	0.064875	0.543501	0.001183	0.458533
Sum	183.6786	189.9801	597.0790	72.06743	639.5954
Sum Sq. Dev.	2.817147	3.081578	0.398931	2.729992	2.245665
Observations	36	36	36	36	36

In Table 2 above presented the descriptive statistics. LNCPI represent the inflation rate, LNEXTCH represent the exchange rate, LNGDP represent the Gross Domestic Product (GDP), LNINRT represent interest rate and LNM2 represent money supply. Inflation and exchange rates are positively skewed while GDP, interest rate and money supply are negatively skewed. Lastly all the macroeconomic variables have low kurtosis values.

Table 3. Correlation Matrix of the endogenous variables and exogenous variables

	lnCpi	lnExch	lnIntrt	lngdp	lnM2
lnCpi	1.0000000	0.9245170	0.6051449	0.7800901	0.9580465
lnExch	0.9245170	1.0000000	0.4493517	0.6169817	0.8699814
lnIntrt	0.6051449	0.4493517	1.0000000	0.5712232	0.5617304
lngdp	0.7800901	0.6169817	0.5712232	1.0000000	0.7843623
lnM2	0.9580465	0.8699814	0.5617304	0.7843623	1.0000000

Table 3 shows the correlation between the endogenous and exogenous variables. The correlation among inflation rate (lnCpi), GDP (lngdp) and Money supply (lnM2) are very high positive. Also high positive correlation existed with exchange rate, GDP and money supply. While low positive correlation existed with interest rate (lnIntrt), GDP and Money supply. In all, positive correlation existed among the endogenous variables and exogenous variables.

Table 4. BVARX lag selection

Lags	AIC	BIC	HQ
[1,]	1 -18.79508	-18.28842	-18.61189
[2,]	2 -19.06200	-18.17534	-18.74141
[3,]	3 -18.78931	-17.52265	-18.33133
[4,]	4 -18.80277	-17.15611	-18.20739

In Table 4 above shows the lag selection criteria for the BVARX models. Using 4 as the maximum lag, the Akaike Information Criterion (AIC); Bayesian Information Criterion (BIC); Hannan and Quinn information Criterion (HQIC) choose lag 2 as the optimal lag for the BVARX models except BIC that choose lag 1. Hence lag 2 was implemented for the BVARX models.

Table 5. Forecast assessment of the BVARX models with respect to the priors

Models	Normal-inverse Wishart		Normal-flat		Flat-Flat	
	RMSE	MAE	RMSE	MAE	RMSE	MAE
BVARX1	0.2092116	0.1476001	0.2092116	0.1476001	0.1818706	0.1461667
BVARX2	0.2100325	0.1481401	0.2100325	0.1481401	0.1818706	0.1461667
BVARX3	0.2141052	0.1444851	0.2141052	0.1444851	0.1905316	0.1520895
BVARX4	0.2195226	0.1487967	0.2195226	0.1487967	0.1905316	0.1520895
BVARX5	0.2208066	0.1502676	0.2208066	0.1502676	0.1905316	0.1520895
BVARX6	0.2105754	0.1483677	0.2105754	0.1483677	0.1818706	0.1461667

The RMSE and MAE were used in model selection among the competing BVARX models across the priors as shown in Table 5 above. The RMSE and MAE values for BVARX models with Normal-inverse Wishart and Normal-Flat are similar, but BVARX model with Flat-Flat prior produce superior models using RMSE while using MAE the result is mixed among the priors and BVARX models. From the econometrics side, BVARX model with Normal-Inverse Wishart prior, the effect of GDP and money supply on inflation rate, exchange rate and interest rate are positive. While BVARX models with Normal-Flat and Flat-Flat priors show effect of GDP on inflation rate and exchange rate is negative and positive for interest rate while money supply effect on inflation rate and exchange rate is positive and negative for interest rate [9,12].

Lastly, among the prior used, the Flat-Flat prior which is non-informative prior is superior over the Normal-Inverse Wishart and Normal-Flat priors.

Table 6. Granger causality test

	F-statistic	p-value
lnExch -> Incpi	0.8863747	0.4230187460
lnInrt -> Incpi	0.6959594	0.5067318796
Incpi -> lnExch	8.9925806	0.0009148303
lnInrt -> lnExch	1.1024179	0.3455838169
Incpi -> lnInrt	2.1339376	0.1365864274
lnExch -> lnInrt	0.7773448	0.4689664530

In Table 6 above, we presented granger causality test for the endogenous variables. Evidence shows that inflation rate granger cause exchange rate in Nigeria [9,12].

5 Conclusion

This present study focused on the dynamic interrelationships among inflation, interest and exchange rates with the effects of money supply and GDP in Nigeria using Bayesian Vector Autoregression with Exogenous variables (BVARX) models. To achieve this, data was sourced from the Central bank of Nigeria (CBN) website spanning the period of 2010Q1-2020Q4. The study proposed six (6) versions of BVARX models with lag 2 using Normal-Wishart, Normal Flat and Flat-Flat priors. The results revealed superior BVARX models with Flat-Flat prior using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) as means of model selection. Lastly, evidence from Bivariate Granger causality testing reveals that the past lag values of inflation rate help in predicting exchange rate in Nigeria.

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Competing Interests

Authors have declared that no competing interests exist.

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