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MONETARY POLICY DYNAMICS IN NIGERIA: EMPIRICAL EVIDENCES FROM BAYESIAN VECTOR AUTOREGRESSION WITH STOCHASTIC VOLATILITY

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ABSTRACT

In this paper, we examine the dynamics of monetary policy in Nigeria with Bayesian approach to a vector autoregression (VAR). We construct and estimate Bayesian Vector Autoregression with Stochastic Volatility (BVAR-SV) model and extract important policy inputs from the model. Nigeria economy is unstable and it is a known fact that changes to monetary policy affects performance of some macroeconomic variables. The BVAR has the ability to capture sudden changes and nonlinearities arising from the interaction among macroeconomic variables and associated shocks. The study uses monthly data during the period 2003M01 till 2023M12 with three macroeconomic variables namely; inflation rate, money supply, and interest rate. A Markov Chain Monte Carlo algorithm that allows for Bayesian estimation and prediction is employed. Results show that there is strong evidence of monetary policy playing a significant role in explaining the dynamics of interest rate while the impulse responses for the variables to a monetary policy shock do change significantly over time. Also, the monetary policy exert less significant influence in terms of money supply and inflation than interest rate in explaining the dynamics in of monetary policy. It is recommended that BVAR should be also be extended to other macroeconomic variables to examine the effects on monetary policy dynamics.

Keywords: Bayesian, Monetary policy, Nigeria, Macroeconomic variables

INTRODUCTION

Monetary policy is the policy adopted by monetary authority (Central banks) of nation to contribute to economy stability or to maintain a predictable exchange rates with other currencies. It is also described as the art of controlling the direction of movement of monetary and credit facilities to stabilize prices and economic growth (CBN, 1992). Monetary policy involves the use of different measures with the aim of regulating the value, supply and cost of money in consonance with the expected level of economic activity (Quartey and Afful-Mensah, 2014).

In Nigeria, the objectives of monetary policy by Central Bank of Nigeria (CBN) particularly focused on the attainment of internal and external balance of payments. However, the ingredients to achieve those objectives are changing overtime. For instance, in year 2011, the maintenance of price stability was the main focus of monetary policy, but in year 2013, monetary policy aimed at sustaining the interest rate that was achieved earlier that year. In 2014, monetary policy focused on achieving price and exchange rate stability.

Recently, the CBN governor outlined some monetary policy in year 2024 by prioritizing price and exchange rate stability to promote sustainable economic growth, safeguarding the livelihoods of Nigeria. Table 1 gives a cursory summary of the targets of CBN on monetary policies.

Table 1: Some monetary policies of Central Bank of Nigeria (CBN)

Year	Focus
2024	Price and exchange rate stability
2021	Easing the impact of shocks on economy(especially on ongoing supply side disruptions associated with the post-lockdown among others)
2020	Strike a balance between supporting the recovery of output growth while maintain stable price developments.
2019	Key developments in the global and domestic economic and financial environments.
2018	Key developments in the global and domestic economic and financial environments.
2017	To stimulate the economy out of recession, and achieve overall macroeconomic stability
2016	Addressing the challenges by adjusting rapidly to avoid further hurting growth and deepening the on-going recession
2015	Market expectations of the normalization of US monetary policy, weak global growth and falling crude oil prices in international markets.
2014	Price and exchange rate stability
2013	Sustaining already moderated rate of inflation

Source: CBN WEBSITE (Central Bank of Nigeria : Monetary Policy Mandate (cbn.gov.ng)*)*

In literature, various key macroeconomic variables have been used to examine the performance of monetary policy on economy of Nigeria. Oseni and Oyelade (2023) investigated the effects of monetary and fiscal policies on economic growth in Nigeria using different economic variables. They affirmed that monetary policy is more effective than fiscal policy in Nigeria.

The effects of monetary policy was investigated on bank lending and economic performance in Nigeria for a period of 35 years by Olofinlade *et al*. 2020. It was discovered that monetary policy positively and significantly influenced economic performance of Nigeria. Also, Muhammed, *et al.* 2021 examined the impact of monetary policy on the Nigerian economy between 1981 to 2016 using vector error correction mechanisms. It was observed that the monetary policy represented by money supply exerts a positive impact on GDP growth.

Balogun (2021) investigated the effect of cash reserve ratio and monetary policy rate of economy of Nigeria. An autoregressive distributed lag test for bound for Cointegration to determine the long run relationships between the variables. It was revealed that there is a long run dynamics of the relationship between the GDP and cash reserve ratio.

Researchers in time series econometrics are recently embracing the Vector autoregression model among several multivariate time series models that have been proposed. Also, due to increase in popularity Bayesian econometrics has enjoyed, many Bayesian Vector autoregression models have been developed for macroeconomics variables. Bayesian VAR models begins with seminal works of Litterman (1979) and Sims (1980), followed by works of Doan *et al.* (1984). Other notable works on Bayesian VAR model in recent years are; Lu, *et al.* (2018), Ojo (2020), Ojo (2021), and Israel, *et al*. (2023) among others.

Stochastic volatility models provide an alternative approach to model time variation in the size of fluctuations Uhlig (1997). It is also attractive because they are close to the models often used in financial theory to represent the behavior of financial prices Assaf (2017). Furthermore, stochastic volatility component allows for time variation in the variance-covariance matrix of the model's forecast errors Clark and Mertens (2023). Hence, Bayesian Vector autoregression model with stochastic volatility (BVAR-SV) leads to the best forecasts. Few works were recorded in literature on BVAR-SV; Uhlig (1997), Onipede, *et al.* (2023), Carriero, *et al.* (2019), Chan, *et al.* (2023).

Uhlig (1997) proposed a Bayesian approach to vector autoregression with stochastic volatility, where the multiplicative evolution of the precision matrix is driven by a multivariate beta variation. Onipede, *et al.* (2023) examined the impact of external shocks on select small open economies (SOEs) using the Bayesian variant of the global vector autoregression model with time varying parameters and stochastic volatility. Three different priors were used in the estimation of the parameters of the model namely; the Minnesota (M-N), the Normal-Gamma (N-G) prior and Stochastic Search Variable Selection (SSVS) priors.

A new Bayesian estimation procedure for VARs featuring time-varying volatilities and general priors was proposed by Carriero, *et al.* (2019). This method is based on a straightforward triangularization of the system, and was discovered to be very simple to implement. The new estimation procedure performs well in applications to both structural analysis and out-of-sample forecasting.

Over the years, Nigeria economy is unstable and it is a known fact that changes to monetary policy affects performance of some macroeconomic variables. Hence, there is need to examine the monetary policy dynamics of Nigeria in order to know how to strengthen it. Also, the CBN has in recent times maintain easy monetary policy by stabilizing the price and exchange rate. BVAR has the ability to capture sudden changes and nonlinearities arising from the interaction among macroeconomic variables and associated shocks. In this work, we construct and estimate monetary policy dynamics of Nigeria using Bayesian Structural Vector Autoregression model with Stochastic Volatility (BVAR-SV) and also extract important policy inputs from the model. For this purpose, three macroeconomic variables namely; inflation rate, money supply, and interest rate will be used. Specifically, we will be following the work of Chan *et al*. (2023) that proposed a method to overcome the problem of lower triangular parameterization in the BVAR with stochastic volatility. Chan, *et al.* (2023) show that the presence of multivariate stochastic volatility allows for identification of the proposed model and prove that it is invariant to ordering and also that the choice of variable ordering have non-negligible effects on empirical results.

The remainder of this paper is organized as follows. In section 2, VAR with stochastic volatility model will be highlighted while the framework of Bayesian estimation method will be also be discussed, this will involves the ordering issues in VAR-SVs. data and also show how to analyze the posterior numerically. Section 3 discusses the results obtained from the analysis. Finally, section 4 concludes.

MATERIALS AND METHODS

This Section gives the model and properties of VAR with stochastic volatility while the framework of Bayesian estimation method will be also be discussed.

The Vector autoregression stochastic volatility (VAR-SV) model

The VAR model is originally written as:

$$y_t = a_0 + \sum_{j=1}^{p} A_J\, y_{t-j} + \varepsilon_t \qquad (1)$$

where y_t is $m \times 1$ vector of observations on m time series variables for $t = 1, \ldots, T$, a_0 is an intercept of $m \times 1$ vector, A_J is $m \times m$ matrix, p is the number of lags and ε_t is $m \times 1$ vector of errors. It is assumed that $\varepsilon_t \sim$ N (0, Σ).

According to Terasvirta (1977) and Terasvirta, *et al.* (2010), the time series variable, y_t is said to be stationary, if the roots of the characteristics of polynomial, $A_j^2 = I_n - \sum_{j=1}^{p} A_J\, z$ are outside the unit circle. Thus, the model in (1) can be denoted in terms of moving average as:

$$y_t = \varepsilon_t + \sum_{j=1}^{\infty} \Theta_j\, y_{t-j} + \varepsilon_{t-j} \qquad (2)$$

where Θ_j is the response function for shocks, ε_t of time series variable, y_t.

The structural VAR model of (1) can also be written as:

$$A y_t = a_0 + A_1\, y_{t-1} + \ldots + A_k\, y_{t-k} + \varepsilon_t \quad \text{for } t = k+1, \ldots, T \qquad (3)$$

Hence, the VAR with Stochastic volatility using the structural form of VAR in (3) can be written as:

$$y_t = a_0 + A(\mathrm{L})\, y_{t-1} + \varepsilon_t \quad \text{for } t = k+1, \ldots, T \qquad (4)$$

$$\varepsilon_t = A^{-1} \Omega_t^{1/2}\, u_t, \;\; u_t \sim \text{iid}\,(0, I_N) \qquad (5)$$

where ε_t and u_t are both N (0, I_N), $A(\mathrm{L}) = A_1\mathrm{L} + A_2 L^2 + \ldots + A_p\, L^p$, Ω_t is a diagonal matrix with jth element, A^{-1} is a lower triangular matrix and for $t = 1, \ldots, T$, the dimension of y_t.

Using stochastic volatility and a factorization of Σ_t that is common in many macroeconomic applications, we have:

$$\Sigma_t = var(\varepsilon_t) = A^{-1}\, \Omega_t\, (A^{-1})'$$

The model in (4) and (5) specifically means that, it has a time varying matrix of Σ_t for the disturbances, ε_t. It is also useful

in any kind of model that has features of a time-varying error variance matrix, in any case how its time variation is modeled. The stochastic volatility of the reduced form errors in (5) can be written as:

$\varepsilon_t = A^{-1}\, u_t,\ u_t \sim$ N (0, D_t)

where A is a unit lower triangular matrix with elements c_{ij} and D_t = diag($e^{h_{1,t}}, \ldots, e^{h_{n,t}}$) is a diagonal matrix which consists the log-volatility $h_t = (h_{1,t} \ldots, h_{n,t})'$.

Bayesian Inference

In order to analyze the model in (4) and (5) using Bayesian approach, one needs to obtain the posterior distribution by choosing an appropriate prior distribution. The appropriate choice of prior allows for flexible treatment in applications and leads to a computationally particularly convenient expression of the posterior distribution Hauzenberger *et al*. (2022). In Bayesian time series study especially in the analysis of macroeconomic time series, the choice of prior has generated a lot of arguments (Uhlig, 1994). Suitable priors can leads to better forecast in the analysis of macroeconomic time series Geweke (1994). Some many priors have been used in literature in analysis of macroeconomic time series, those priors are Bernardo's prior by Bernardo (1979), Bayes-Laplace uniform prior by Berger (1985), Normal-Wishart (N-W) prior by Bekker and Roux (1995) e.t.c. Here, we will use Normal-Wishart (N-W) prior. Normal-Wishart (N-W) is a conjugate prior, it has the advantages of less computationally effective and also have the same functional form with posterior distribution and is stated as:

vec(A)~ N (vec ($\underline{\mu}_A$), $\underline{\Psi}_A$) (6)

$\Sigma|\pi, y_t \sim IW$ ($\underline{d}_\Sigma\ \underline{\Sigma}$, $\underline{d}_\Sigma$) (7)

The likelihood function for equations in (4) and (5) is given as:

P ($y_t\,|A_o\,, h$) = $(2\,\pi)^{-\frac{nT}{2}}$ |det $A_o|'$ $\prod_{t=1}^{T} |\det D_t|^{-1/2}$ $e^{-1/2\sum_{t=1}^{T} y_o'\ A_o' y D_t^{-1} A_O y_t}$ (8)

where |det A| is the absolute value of determinant of square matrix of C, we can therefore permutate the dependent the variables.

Hence, let Q be an arbitrary permutation matrix of dimension n. If the variable is changed using the definition $\tilde{y} = Qy_t$, we therefore write the likelihood as:

=$(2\quad \pi)^{-\frac{nT}{2}}$ |det $\widetilde{A_o}|'$ $\prod_{t=1}^{T} |\det \widetilde{D_t}|^{-1/2}$ $e^{-1/2\sum_{t=1}^{T} \widetilde{y_o'}\ \tilde{A}_o' y\, \widetilde{D}_t^{-1} \tilde{A}_O \tilde{y}_t}$ (9)

Combining priors and likelihood gives the following posterior distribution:

vec(A)$|\Sigma, y_t \sim N$ (vec ($\hat{\mu}_A$), $\widehat{\Omega}_\pi$) (10)

$\Sigma|\pi, y_t \sim IW$ (($\underline{d}_\Sigma$ + T) $\overline{\Sigma}$, $\underline{d}_\Sigma$ + T) (11)

where

$\overline{\Psi}_A^{-1} = \underline{\Psi}_A^{-1} + \sum_{t=1}^{T}(\Sigma^{-1} \text{ג} \otimes X_t\, X_t')$

Equations (10) and (11) show that conjugacy have been achieved. Conjugacy results was also established in Uhlig (1994).

Data presentation

The data used for this study are secondary and are sourced from Central Bank of Nigeria statistical bulletin, Economic and Financial Review and Annual Reports were also used. The study uses monthly data during the period 2003M01 till 2023M12. In estimating the BVAR-SV model, we focus on three macroeconomic variables namely; inflation rate, money supply, and interest rate following the methods proposed by Chan *et al*. (2023) to see the impact of monetary policy on the macroeconomic variables. The money supply was transformed while the datasets are applied using the standard priors (independent Normal-Wishart for the BVAR-SV coefficients prior form). The Markov Chain Monte Carlo (MCMC) procedure (see Yang et al. (2022) and Ausin and Galeano (2007) for more details) were employed to obtain the estimates for the parameters.

The hyperparameters are sets as:

$\underline{\mu}_A = 0_p\ \underline{\Psi}_A = I_3\ \ \underline{d}_\Sigma = 0, \underline{\Sigma} = 0.01 I_k$ for the models

The posterior results for the model are based on 20000 replications, with Burn-in period of 1000.

Forecast evaluation

The forecast evaluation criteria that will be considered are; Root Mean Squares Error (RMSFE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE)

Root Mean Squares Error (RMSE)

The RMSE is defined as:

$= \sqrt{\frac{1}{n}\sum_{t=1}^{n}(y_t - y_t^f)^2}$

where y_t^f is predicted in-sample of y, y_t is the time series data, and n is the number of observation.

Mean Absolute Error (MAE)

This MAE can be computed as:

$= \frac{1}{n}\sum_{t=1}^{n} |y_t^f - y_t|$

Mean Absolute Percentage Error (MAPE)

$= 100 \sum_{t=1}^{n} |\frac{y_t^f - y_t}{y}|$

RESULTS AND DISCUSSION

This Section contains the empirical results of method and data highlighted in methodology and data presentation, respctively. The summary statistics is presented in Table 2. It gives idea about the dataset. Money supply is the least performing Macroeconomics variable of monetary policy of Nigeria. It has the mean of 4.6578. Interest rate recorded the highest and lowest rate. The estimate of Bayesian Structural Vector Autoregression model with Stochastic Volatility (BVAR-SV) were recorded for monetary policy dynamics of Nigeria in Table 3. The table revealed the posterior means and standard deviation of the macroeconomic variables. Each column represent a BVAR-SV equation. The price stability objective via monetary policy can be achieved by using the value of parameters. It is apparent that interest rate has significant effect on monetary policy followed by money supply. This shows the effectiveness of the monetary policy in achieving price stability objective. It also suggests that CBN should responds with expansionary monetary policy to boost economic activity by keeping interest rates low to encourage borrowing. In Table 4, forecast of the models for the three macroeconomic variables were carried out. Results for three different forecast horizons (h =1, 6, and 12) are presented. We use the iterated method of forecasting to compute longer horizon forecasts. The forecast performance of the models is evaluated from 2021:03 till the end of the sample. The forecast evaluation methods are; Root mean square error (RMSE), Mean absolute error (MAE), and Mean absolute percentage error (MAPE). Root mean squared forecast errors (RMSFEs) are used to evaluate the quality of point forecasts while MAE measures the errors between paired observations. Also, MAPE measures the prediction accuracy of forecasting method. The results for forecast horizons are not different from each other. It is observed that MAE and MAPE have the same pattern of forecast for money supply having the minimum forecasts while the interest rate has the minimum forecast in terms of RMSE.

Table 2: Summary statistics

	Inflation	Money supply	Interest rate
Mean	12.7518	4.6578	11.1800
Median	12.1000	4.6577	10.5000
Minimum	3.0000	4.6561	0.0000
Maximum	28.9200	4.6594	64.5800
Standard deviation	4.7202	0.0010	7.8900

This is an indication that interest rate and inflation play great role in monetary policy of Nigeria. And these also determine the level of economic growth in the country. Figure 1 indicates the same pattern for all the variables (inflation rate, money supply, and interest rate). However, inflation rate and interest rate have minimum standard error.

Table 3: Posterior results for BVAR-SV

Variables	INF	MONEYSUP	INTRATE
constant	0.0435	1.5006	0.5241
	(0.8071)	(1.8964)	(0.3529)
INF(-1)	1.5353	0.0001	0.5293
	(0.8964)	(1.4279)	(0.3798)
INF(-2)	0.0266	0.5458	0.2222
	(0.8868)	(1.2450)	(0.4517)
MONEYSUP(-1)	-0.0070	0.0001	0.4881
	(0.9268)	(1.3136)	(0.4379)
MONEYSUP(-2)	-0.5297	-0.0001	-0.4750
	(0.0328)	(1.4707)	(0.4216)
INTRATE(-1)	-0.0156	0.1320	0.2355
	(0.0341)	(1.3616)	(0.4247)
INTRATE(-2)	-0.0031	0.0001	0.2101
	(0.0425)	(1.4777)	(0.5033)

() indicates standard deviation

Table 4: Forecast for three macroeconomic time series

	RMSE			MAE			MAPE		
	$h=1$	$h=6$	$h=12$	$h=1$	$h=6$	$h=12$	$h=1$	$h=6$	$h=12$
Inflation	6.7333	6.7574	6.8224	5.8302	5.8630	5.8484	32.0416	33.4422	33.5858
Money supply	8.0249	8.4928	9.0233	0.0004	0.0005	0.0009	0.0185	0.0265	0.0282
Interest rate	0.0010	0.1933	0.3043	5.5392	5.6194	5.6318	42.3243	42.6331	43.9222

Figures 2 and 3 present the Impulse-Responses (IRFs) of inflation rate, money supply and, interest rate to Nigeria monetary policy. From the results, different patterns were observed across the months. It reveals that shocks occurring in each month has different impact. Money supply shock lead to the largest shock in monetary policy of Nigeria. Also, transmission mechanism and the variance of the exogenous shocks for the Nigerian economy are time varying.

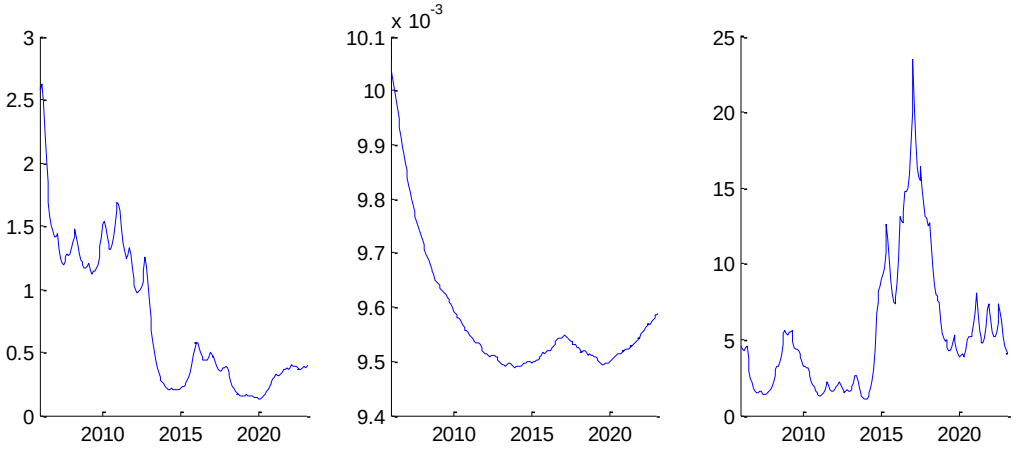

Figure 1: Estimated time-varying reduced-form variances of inflation (left panel), Money supply (middle panel), and Interest rate (right panel) with stochastic volatility.

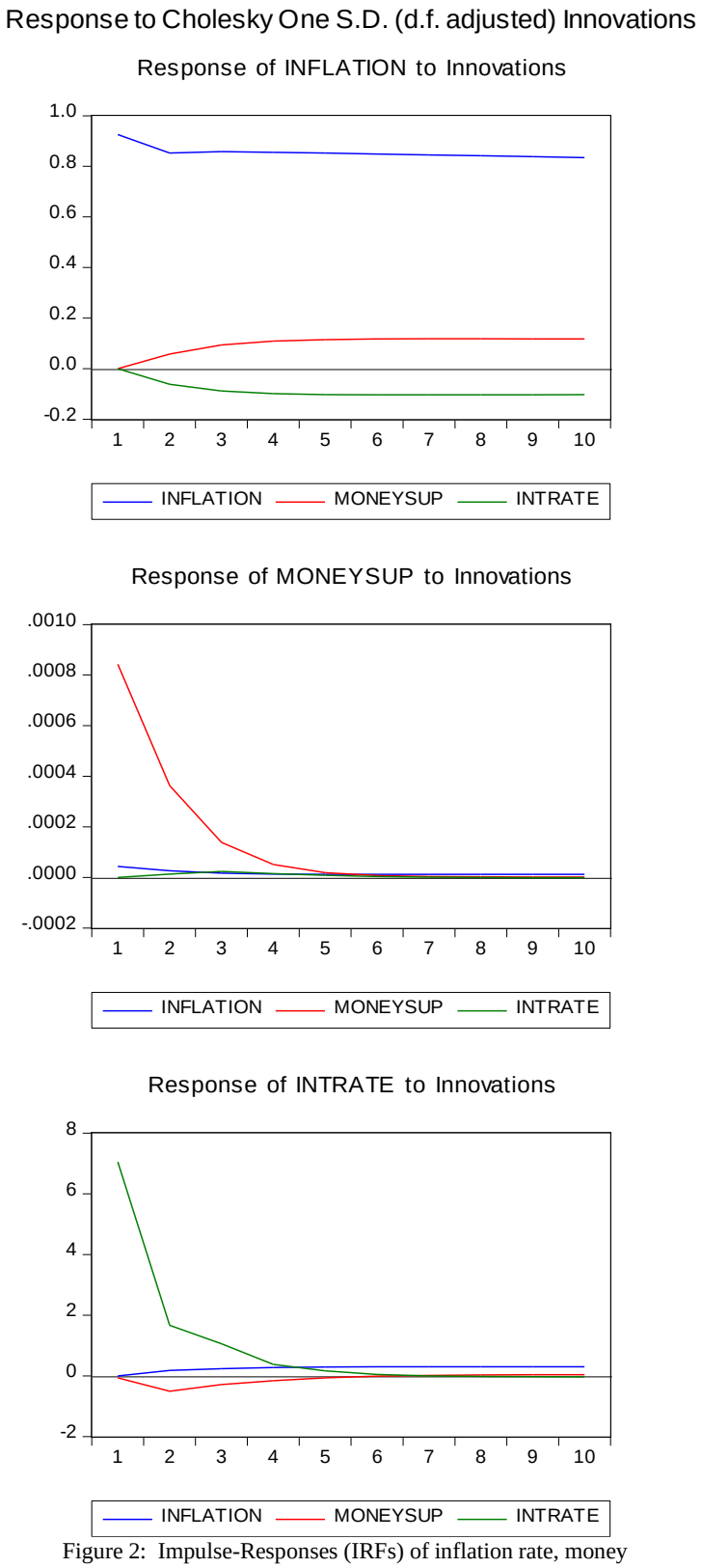

Figure 2: Impulse-Responses (IRFs) of inflation rate, money supply and, interest rate to monetary policy shock of Nigeria

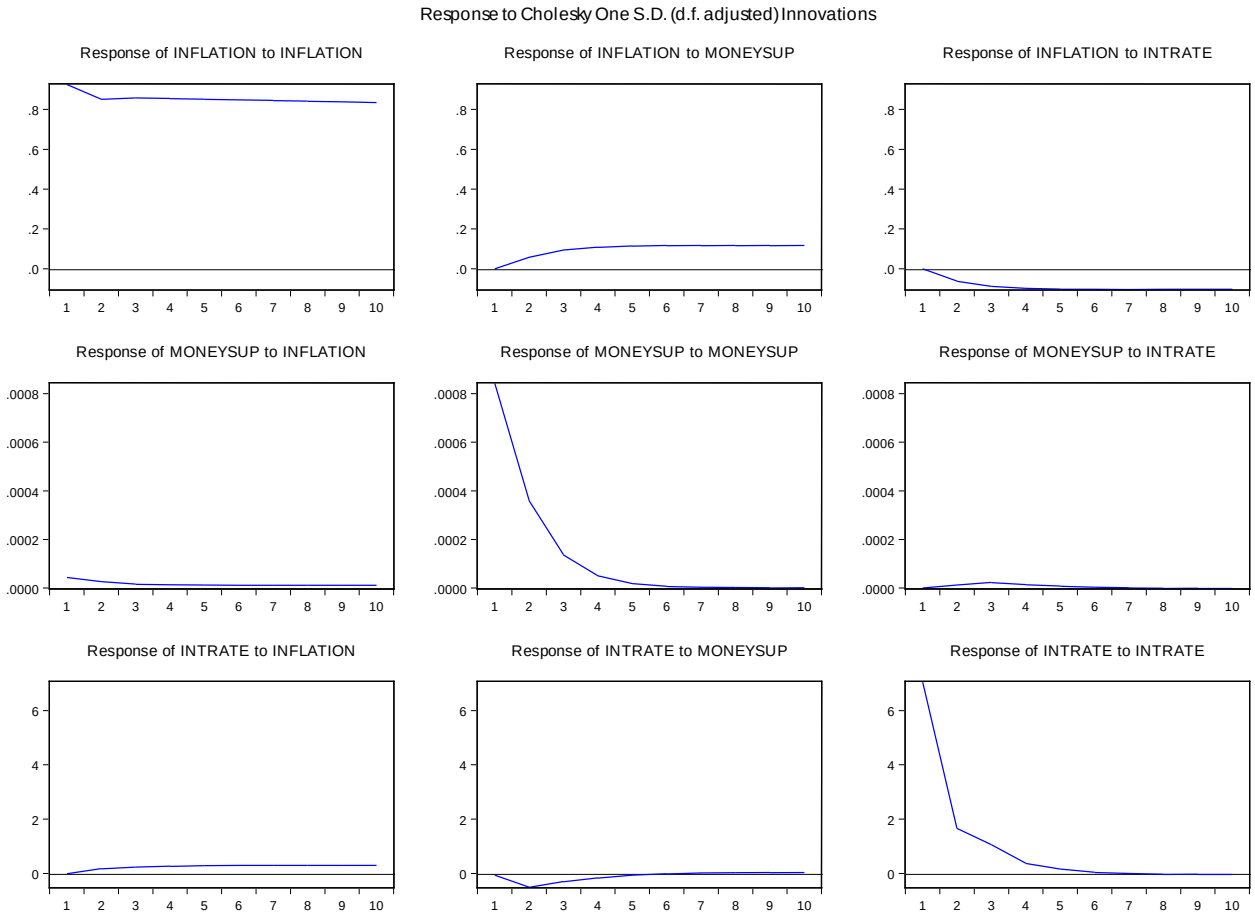

Figure 3: Impulse-Responses (IRFs) of inflation rate, money supply and, interest rate to monetary policy shock of Nigeria

CONCLUSION

The focus of this study is to construct and estimate monetary policy dynamics of Nigeria using Bayesian Vector Autoregression model with Stochastic Volatility (BVAR-SV) and also extract important policy inputs from the model. For this purpose, three macroeconomic variables namely; inflation rate, money supply, and interest rate were used. To examine the performance of these macroeconomic variables of the monetary policy, we used monthly data from 2003:1 to 2023:12. A Markov Chain Monte Carlo algorithm that allows for Bayesian estimation and prediction was employed.

Specifically, the paper examines the role of monetary policy in the dynamics of inflation rate, money supply, and interest rate in Nigeria using Bayesian Vector Autoregression model with stochastic volatility models. The findings from the study revealed that there is a strong evidence of monetary policy playing a significant role in explaining the dynamics of interest rate as the impulse responses for the variables to a monetary policy shock do change significantly over time.

Interest rate has significant effect on monetary policy followed by money supply. This shows the effectiveness of the monetary policy in achieving price stability objective. Also, transmission mechanism and the variance of the exogenous shocks for the Nigerian economy are time varying. Therefore, the study suggests that CBN should responds with expansionary monetary policy to boost economic activity by keeping interest rates low to encourage borrowing.

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