Economics Bulletin

Volume 36, Issue 4

Time-Varying VAR with Stochastic Volatility and Monetary Policy Dynamics in Nigeria

Bala Dahiru Abdullahi
Department of Economic Engineering, Kyushu University, Fukuoka, Japan.

Abstract

This paper examines the impact of monetary policy on real-GDP, foreign-exchange (FX) reserves and inflation dynamics in Nigeria from 1970Q1 to 2014Q2 by estimating a time-varying parameter-VAR (TVP-VAR) with stochastic volatility model. The model is employed due to its flexibility and its ability to capture both gradual and sudden changes and in dealing with nonlinearities arising from the interaction among macroeconomic variables and associated shocks. In addition, both the coefficients and the variance-covariance matrix of the model's innovations are time varying. The paper finds strong evidence of monetary policy playing a significant role in explaining the dynamics of inflation as the impulse responses for the variables to a monetary policy shock do change significantly over time. However, we observe that monetary policy shocks exert less significant influence than other exogenous non-policy shocks in explaining the dynamics in real-GDP and FX reserves. We also find that the transmission mechanism and the variance of the exogenous shocks for the Nigerian economy are time varying.

The author expresses sincere gratitude to Mohammed Bala Audu, anonymous referee and the editor for the constructive comments, suggestions and contributions. All other remaining errors are my responsibility.
Citation: Bala Dahiru Abdullahi, (2016) "Time-Varying VAR with Stochastic Volatility and Monetary Policy Dynamics in Nigeria", *Economics Bulletin*, Volume 36, Issue 4, pages 2237-2249
Contact: Bala Dahiru Abdullahi - audubm@yahoo.co.uk.
Submitted: September 11, 2015. **Published:** November 27, 2016.

1 Introduction

The vector autoregression (VAR) modelling technique has evolved into an important tool for analysing the dynamics of economic and financial variables and in the assessment of the impact of macroeconomic policies (see, Primiceri, 2005; Koop *et al.*, 2009 and Kapetanios *et al.*, 2012, among others). By the late-1990s, VAR models have been extended to incorporate time-varying components (see, Uhlig, 1997). This is partly because several studies have highlighted that some of the model's assumptions (e.g. the assumption of constant variance) are restrictive due to the neglect of possible time variation. Recently, a time-varying parameter-VAR (TVP-VAR) with stochastic volatility (SV) model, proposed by Primiceri (2005) have been used to examine possible changes in the underlying structure of an economy; with the model extended by Koop *et al.* (2009) and recently by Liu and Morley (2014), among others. We employ the TVP-VAR-with-SV model in this paper as new studies such as D'Agostino *et al.* (2010) argue that forecasts from TVP-VAR models may be an improvement on forecasts from the constant parameter-VAR type models. Over the years, monetary authorities have raised and cut interest rates in order to check inflation and to pursue their monetary policy objectives in Nigeria. Recently, rising interest rates, inflation and exchange-rate volatility have become a source of concern over their potential to stifle growth and undermine economic stability. Consequently, the Central Bank of Nigeria (CBN) raised the monetary policy rate (MPR) from 6% in 2010Q1 to 13% in 2015Q1 and devalued the currency (the *Naira*) against the US dollar. This is to check rising inflation, defend the external reserves and to influence economic activities. Nigeria's inflation rate has since declined from 13% in 2010Q2 to 8.4% in 2015Q1 (CBN, 2015).

Since 2004, Nigeria has experienced significant growth in foreign-exchange (FX) reserves and decline since 2009 due to fluctuations in oil prices arising from increasing oil demand, particularly from India and China and the effects of the global financial crisis (GFC) that led to oil price declines and recession in both industrialised and emerging economies. This has impacted negatively on key macroeconomic variables. Over-reliance on oil exports for over 90% of Nigeria's FX earnings make its capital account susceptible to oil price fluctuations. This has been exacerbated by high imports that have contributed to fluctuations in exchange rates. Nigeria's FX reserves peaked at $64 billion in 2008 before the GFC and stands at $29.8 billion in April, 2015 (CBN, 2011, 2015). Consequently, Nigeria's external sector fluctuations exert pressure on fiscal and monetary policies; undermining the attainment of macroeconomic stability and growth. Exchange-rate volatility impacts on FX reserves and this indirectly has implication for domestic prices. The need to finance current account deficits, imports and to defend the *Naira* exchange rate *vis-à-vis* other major currencies make the stability and stockpiling of FX reserves crucial for the Nigerian economy. Suffice to note that significant fluctuations in macroeconomic variables are often associated with uncertainty and volatility. That is why stochastic volatility plays an important role in TVP-VAR model estimation and analysis.

There is now a growing literature on the analysis of changes in the conduct of monetary policy and their impact on macroeconomic variables. Primiceri (2005) and Cogley & Sargent (2005) both employ TVP-VAR models in order to assess the role of monetary policy in the dynamics of inflation and overall macroeconomic performance with Koop *et al.* (2009) extending their specifications through the use of mixture innovation model. The model takes into account structural breaks and is designed in such a way that the transmission mechanism, the parameters, volatility of exogenous shocks and the covariance matrix change over time (see, Gerlach *et al.*, 2000 and Giordani & Kohn, 2008). The main contribution of Primiceri (2005), Cogley & Sargent (2005), Koop *et al.* (2009) and Liu & Morley (2014) is the incorporation of stochastic volatility into VAR methodology and analysis. Furthermore, numerous studies have employed the TVP-VAR model to examine key macroeconomic issues in different ways. Benati

(2008) for instance, applies the TVP-VAR model to examine the time-varying structure of the UK economy by imposing sign restrictions on the impulse response functions (IRFs) in the assessment of the "great moderation" in the UK and inflation forecast uncertainty. Similarly, Baumeister *et al.* (2008) estimate the TVP-VAR model for the Euro-zone to assess the impact of excess liquidity shocks on selected macroeconomic variables. D'Agostino *et al.* (2010) compare the forecast performance of the constant parameter-VAR with the TVP-VAR model. In developed economies, particularly after the GFC, monetary authorities reacted with a variety of conventional and unconventional measures such as quantitative easing (QE), zero interest rates and now negative interest rate policies in order to mitigate the effects of such fluctuations on financial and economic stability. Nakajima *et al.* (2011) estimate the TVP-VAR model using Japan's macroeconomic time series while Kapetanios *et al.* (2012) examine the macroeconomic impact of QE on UK's economy.

In terms of the structure of TVP-VAR model, Primiceri (2005) highlights that "the drifting coefficients are meant to capture possible nonlinearities or time variation in the lag structure of the model". He further states that "the multivariate stochastic volatility is meant to capture possible heteroscedasticity of the shocks and nonlinearities in the simultaneous relations among the variables of the model". Recently, Kapetanios *et al.* (2012) argue that the TVP-VAR model is substantially more flexible than other time-varying VAR models including the Markov-Switching-VAR (MS-VAR) model. They state that "it is not only consistent with variation in policy rule but also consistent with deviation from the rational expectations hypothesis". Furthermore, they claim that the model seems quite plausible during crisis periods where agents have no idea of how shocks have changed the structure of the economy.

We employ the TVP-VAR model of Primiceri (2005) due to a number of reasons. Firstly, we use the TVP-VAR model due to its flexibility and its ability to capture both gradual and sudden changes in the underlying economic structure and possible nonlinearities that may emerge. Secondly, because it enables the shocks to vary over time, as allowing the volatility of errors to be time-varying is now becoming increasingly important in empirical macroeconomics due to the fact that many issues of macroeconomic policy hinge on these changes. Thirdly, the analyses of the impact of monetary policy on key economic variables are still unclear and often inconclusive with the results mainly depending strongly on the methodologies used many of which are restrictive. Finally, to provide empirical evidence on the structural shocks that might be crucial in explaining fluctuations in the Nigerian economy. The rest of the paper is structured as follows: Section 2 examines the monetary policy transmission mechanism in Nigeria while Section 3 outlines TVP-VAR with stochastic volatility methodology. Section 4 describes the data, forecast error variance decomposition (FEVD) and discusses implications of the estimated TVP-VAR with stochastic volatility model while Section 5 concludes. Additional graphs are presented in the Appendix.

2 Monetary Policy Transmission Dynamics in Nigeria

The Nigerian economy has experienced structural changes and several shifts in monetary-policy regimes since the mid-1980s. These changes imply that standard VAR models with constant parameters and homoscedastic shocks mainly used by scholars to examine the issues in Nigeria will often be inadequate in the analysis of the dynamics and structure of the economy. This paper examines the role of monetary policy in the dynamics of inflation, FX reserves (FXR) and real-GDP (RGDP) in Nigeria using mainly Bayesian approach in the estimation of TVP-VAR with stochastic volatility model. Specifically, we investigate to what extent monetary policy shocks impact on the key variables of RGDP, FX reserves and CPI inflation rate. Similar to

Primiceri (2005) we focus on the role of heteroscedastic non-policy innovations.

A significant event with implications for macroeconomic policy for the Nigerian economy is the GDP re-basing exercise which began in late 2011. Re-basing reveals a more accurate estimate of the size and structure of the economy by incorporating new economic activities which were not previously captured in the computational framework. The number of economic activities reported in the computational framework increased from 33 to 46. With the recent re-basing of the GDP to $509 billion, Nigeria became Africa's largest economy overtaking South Africa in 2013 [*National Bureau of Statistics* (NBS), 2014, p.8]. The monetary policy framework in Nigeria presuppose that changes in money supply and other macroeconomic aggregates will work via some intermediate variables through which some effects are transmitted to the ultimate goals of monetary policy. Thus, monetary policy is formulated with some guiding assumptions of the path through which monetary policy impacts on the overall economy. This is referred to as the monetary policy transmission mechanism. It defines the various channels through which changes in the nominal money stock or the short-term nominal interest rate affects prices and output in the economy (CBN, 2011). Of note is the fact that the transmission mechanism of monetary policy is quite complex and could be analysed from different angles and dimension and may operate to reinforce each other.

From Figure A.1 (see Appendix), the monetary transmission channels include the interest rates, exchange rate, asset price, credit and balance sheet channels, among others. With regards to the exchange rate, monetary policy is thought to have a transmission channel to prices and output through the exchange rate since Nigeria is an open economy and the credit channel operates through the bank lending and balance-sheet channels. For the asset-price channel, the adjustments to a portfolio results in increased expenditure by investors; and through that, to output and prices with the outcome depending on the underlying assumptions. Often, Tobin's q is viewed as operating as a channel through which monetary policy shocks get transmitted to investment in the real sector. The balance-sheet channel is equally a significant channel in the overall transmission mechanism (see, CBN, 2011). In the context of financial markets' imperfections, a firm's cost of credit rises when the strength of its balance sheet deteriorates. A direct effect of monetary policy on the firm's balance sheet comes about when an increase in interest rates increase the payments that the firm must make to service its floating rate. An increase in the interest rate not only depresses spending through the traditional interest rate channel, but also raises each firm's cost of capital through the balance-sheet channel, deepening and extending the initial decline in output and employment (with a lag) (CBN, 2011). This channel shows how monetary policy affects the credit portfolio of financial and economic units.

Similarly, Doguwa and Essien (2013) highlight the role and importance of the CBN's analytical balance sheet and monetary survey in monetary policy strategy and implementation. For emerging economies, the relative strengths and weaknesses of monetary policy transmission channels is still not fully understood. That is why the analysis of how monetary policy decisions impact on the real economy are still not fully clear. Besides, structural rigidities constrain the efficient transmission of monetary policy impulses to the real economy, creating the impression that monetary policy is largely inactive (CBN, 2011). Furthermore, the transmission mechanism of monetary policy is time varying as changes are bound to occur over time. The CBN (2011) states that "some channels that used to be very strong either get degraded in importance or become outright irrelevant" with time. These concerns are the main justification for employing the TVP-VAR-with-SV model in this paper as the linear VAR models which are at best an approximation to the TVP-VAR-with-SV model could not handle these issues of interest. The next section outlines the TVP-VAR with stochastic volatility methodology.

3 The Model: TVP-VAR with Stochastic Volatility

This section presents the methodology and properties of the TVP-VAR with stochastic volatility model. Formally, a vector autoregression (VAR) process can be defined as

$$\boldsymbol{y}_t = \sum_{i=1}^{p} \boldsymbol{\Phi}_i \boldsymbol{y}_{t-i} + \boldsymbol{\varepsilon}_t, \qquad \boldsymbol{E}(\varepsilon_t \varepsilon_t') = \boldsymbol{\Sigma}, \tag{1}$$

where $\boldsymbol{y}_t$ is an n-vector of variables, $\boldsymbol{\Phi}_i$ is an $n \times n$ matrix, p is the number of lags and $\boldsymbol{\Sigma}$ is the covariance matrix. The vector time series $\boldsymbol{y}_t$ is stationary if the roots of the characteristic polynomial $\boldsymbol{\Phi}(z) = \boldsymbol{I}_m - \sum_{i=1}^{p} \boldsymbol{\Phi}_i z^i$ are outside the unit circle (Teräsvirta *et al.*, 2010). Under stable conditions, the process in (1) is denoted by the moving average (MA) in (2)

$$\boldsymbol{y}_t = \boldsymbol{\varepsilon}_t + \sum_{i=1}^{\infty} \boldsymbol{\Theta}_i \boldsymbol{\varepsilon}_{t-i}. \tag{2}$$

The $\boldsymbol{\Theta}_i$ matrix represents the response function to shocks $\boldsymbol{\varepsilon}_t$ of the elements of $\boldsymbol{y}_t$. From (1) and (2), it is assumed that the variables impact on each other according to how they are ordered. We begin with the basic structural-VAR model which is given by

$$A\boldsymbol{y}_t = \boldsymbol{A}_1^* \boldsymbol{y}_{t-1} + ... + \boldsymbol{A}_k^* \boldsymbol{y}_{t-k} + \boldsymbol{\varepsilon}_t, \qquad t = k+1, ..., T, \tag{3}$$

where $\boldsymbol{y}_t$ is the $k \times 1$ vector of observed variables and A, $\boldsymbol{A}_1^*, ..., \boldsymbol{A}_k^*$ are $k \times k$ matrices of coefficients while the innovation term $\boldsymbol{\varepsilon}_t$ is a $k \times k$ structural shock. Accordingly, (3) which is a structural-VAR can be specified in another form. Consider

$$\boldsymbol{y}_t = \boldsymbol{c}_t + \boldsymbol{B}_{1,t} \boldsymbol{y}_{t-1} + ... + \boldsymbol{B}_{k,t} \boldsymbol{y}_{t-k} + \boldsymbol{\varepsilon}_t, \qquad t = k+1, ..., T, \tag{4}$$

where $\boldsymbol{y}_t$ is an $n \times 1$ vector of observed endogenous variables, $\boldsymbol{c}_t$ is an $n \times 1$ vector of time-varying intercepts and $\boldsymbol{B}_{i,t}, i = 1, ..., k$, are $n \times n$ matrices of time-varying coefficients while $\boldsymbol{\varepsilon}_t$ are heteroscedastic unobservable shocks with variance-covariance matrix $\boldsymbol{\Omega}_t$. Primiceri (2005) considers the triangular reduction of $\boldsymbol{\Omega}_t$ to be defined as: $\boldsymbol{A}_t \boldsymbol{\Omega}_t \boldsymbol{A}_t'$. Hence, $\boldsymbol{A}_t$ which is a lower-triangular matrix and $\boldsymbol{\Sigma}_t$ are defined as

$$\boldsymbol{A}_t = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{n1,t} & \cdots & \alpha_{nn-1,t} & 1 \end{pmatrix}, \boldsymbol{\Sigma}_t = \begin{pmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{n,t} \end{pmatrix},$$

where $\boldsymbol{\Sigma}_t$ is a diagonal matrix. There are several ways to model the VAR process for time-varying parameters already proposed in the literature. Equation (3) can be expressed as a reduced-form VAR model which is given by

$$\boldsymbol{y}_t = \boldsymbol{B}_{1,t} \boldsymbol{y}_{t-1} + ... + \boldsymbol{B}_{k,t} \boldsymbol{y}_{t-k} + \boldsymbol{A}^{-1} \Sigma \boldsymbol{\varepsilon}_t, \qquad \boldsymbol{\varepsilon}_t \sim N(\boldsymbol{0}, \mathbf{I}_k), \tag{5}$$

whereby, in the context of time-varying parameter (TVP) modelling we have

$$\boldsymbol{y}_t = \boldsymbol{c}_t + \boldsymbol{B}_{1,t} \boldsymbol{y}_{t-1} + ... + \boldsymbol{B}_{k,t} \boldsymbol{y}_{t-k} + \boldsymbol{A}_t^{-1} \boldsymbol{\Sigma}_{\boldsymbol{t}} \boldsymbol{\varepsilon}_t, \qquad V(\boldsymbol{\varepsilon}_t) = \boldsymbol{I}_n, \tag{6}$$

where $\boldsymbol{A}_t$ is a lower-triangular matrix with ones on the main diagonal and time-varying coefficients below it, $\boldsymbol{\Sigma}_t$ is a diagonal matrix of time-varying standard deviations and $\boldsymbol{\varepsilon}_t$ is an $n \times 1$ vector of unobservable shocks with variance equal to the identity matrix. From (3) we let $\boldsymbol{B}_i = A^{-1} \mathbf{A}_i^*$ for $i = 1, ..., k$. Stacking the elements in the rows of the $\boldsymbol{B}_i$'s and defining $\boldsymbol{X}_t = \boldsymbol{I}_k \otimes (\boldsymbol{y}_{t-1}', ..., \boldsymbol{y}_{t-k}')$, the model can be represented by

$$\boldsymbol{y}_t = \boldsymbol{X}_t \boldsymbol{\beta} + \mathbf{A}^{-1} \boldsymbol{\Sigma} \boldsymbol{\varepsilon}_t, \tag{7}$$

where $\otimes$ denotes the Kronecker product. All the parameters in (7) are constant (time-invariant). TVP-VAR models extend (7) by allowing the parameters to change over time. Again, by stacking in a vector $\boldsymbol{B}_t$ for all the right hand side (R.H.S.) coefficients, (6) can be represented more compactly as

$$\boldsymbol{y}_t = \boldsymbol{X}_t'\boldsymbol{B}_t + \boldsymbol{A}_t^{-1}\boldsymbol{\Sigma}_t\boldsymbol{\varepsilon}_t, \tag{8}$$

where $\boldsymbol{X}_t' = \boldsymbol{I}_n \otimes [1, \boldsymbol{y}_{t-1}', ..., \boldsymbol{y}_{t-k}']$ and $\boldsymbol{B}_t, \boldsymbol{A}_t$ and $\boldsymbol{\Sigma}_t$ are all time varying. Following Primiceri (2005), let $\boldsymbol{\alpha}_t = (\alpha_{21,t}, \alpha_{31,t}, \alpha_{32,t}, \alpha_{41,t}, ..., \alpha_{nn-1,t})'$ be a stacked vector of the lower-triangular elements in $\boldsymbol{A}_t$ and $\boldsymbol{\sigma}_t = (\sigma_{1t}, ..., \sigma_{n,t})'$ be the vector of the diagonal elements of the matrix $\boldsymbol{\Sigma}_t$. It suffices to state that allowing the matrix $\boldsymbol{A}_t$ to change over time is crucial in TVP-VAR model analysis. When parameters in (8) follow a random walk (RW) process, the dynamics of TVP are

$$B_t = B_{t-1} + \nu_t, \quad \alpha_t = \alpha_{t-1} + \zeta_t, \quad log\sigma_t = log\sigma_{t-1} + \eta_t. \tag{9}$$

The standard deviations (σ_t) are assumed to evolve as a geometric RW belonging to the stochastic volatility model family. The key difference is that the variances estimated from $log\sigma_t$ are unobservable components. All the innovation terms in the model are assumed to be jointly normally distributed with the following assumptions on the variance-covariance matrix

$$\boldsymbol{V} = Var\begin{pmatrix}\varepsilon_t\\ \nu_t\\ \zeta_t\\ \eta_t\end{pmatrix} = \begin{pmatrix}\boldsymbol{I}_4 & 0 & 0 & 0\\ 0 & \boldsymbol{Q} & 0 & 0\\ 0 & 0 & \boldsymbol{S} & 0\\ 0 & 0 & 0 & \boldsymbol{W}\end{pmatrix},$$

where $\boldsymbol{I}_4$ is a 4-dimensional identity matrix, $\boldsymbol{Q}, \boldsymbol{S}$ and $\boldsymbol{W}$ are all positive definite matrices. These parameters govern the variance and covariance structure for the innovation terms of the time-varying parameters. Following Primiceri (2005) we assume that $\boldsymbol{S}$ is block diagonal. The priors are calibrated following Primiceri (2005) and Del Negro & Primiceri (2015) with few modifications. The estimation of these parameters rely on Markov Chain Monte Carlo (MCMC) techniques (see, Liu & Morley, 2014). It suffices to highlight and clarify a very important issue that often arise in the estimation of TVP-VAR-type models. Josfidis *et al.* (2014) aptly state that "it is not necessary to test the stationarity and the cointegration of the model's variables by following the postulates of Sims (1988) and Sims & Uhlig (1991), because a Bayesian inference is used and the model is not then affected by the presence of unit roots". The data and discussion of results are presented in the next section.

4 The Data and Discussion of Results

4.1 The Data

Data used are Nigeria's quarterly macroeconomic time series from 1970Q1 to 2014Q2 consisting of interest rate, FX reserves (FXR), CPI inflation rate (percent change over previous year calculated from indices) and real-GDP. The RGDP data was taken from the CBN database while all other variables were extracted from the IMF's *International Financial Statistics* (IFS) CD ROM (2015). On the data transformation method, particularly on the standard VAR and forecast error variance decomposition (FEVD) estimation, we use log-difference for the RGDP and FX reserves with the exception of interest and CPI inflation rates. However, for the TVP-VAR estimation, we use log-levels for the variables with the exception of those already expressed in rates. The percent change CPI inflation rate was at its highest level in the mid-1990s, before declining substantially by the end of the 1990s. This reduction in inflation was due to the contractionary monetary policy stance of the CBN in the mid-1990s. A significant decline was recorded around 2002. The inflation rate dropped consistently from 2006Q1 to 2008Q1 and by mid-2008 the rates increased again.

4.2 Discussion of Results

4.2.1 Forecast Error Variance Decomposition (FEVD)

We first fit a standard VAR model with two lags as selected by the Akaike information criterion (AIC) before examining the FEVD of the variables considered. The identifying assumptions for monetary policy shock assumes that monetary policy decisions affect real-GDP, CPI inflation rate, and FX reserves with atleast two-period lags. Thus, the interest rate variable is ordered last in the VAR system. Table 1 present results of the FEVD for the four variables with a forecast horizon of 12 quarters. Each column in Table 1 represents a shock while each row represents a forecast horizon. The selected variables being stationary, the 2nd column (which have the forecast error variance itself) converged quickly as well as the percentages. However, the reverse is the case for non-stationary time series. The FEVD tells the economic significance of responses and reveals whether they produce any significant movement in the other variables, but it does not reveal whether a response is statistically significant.

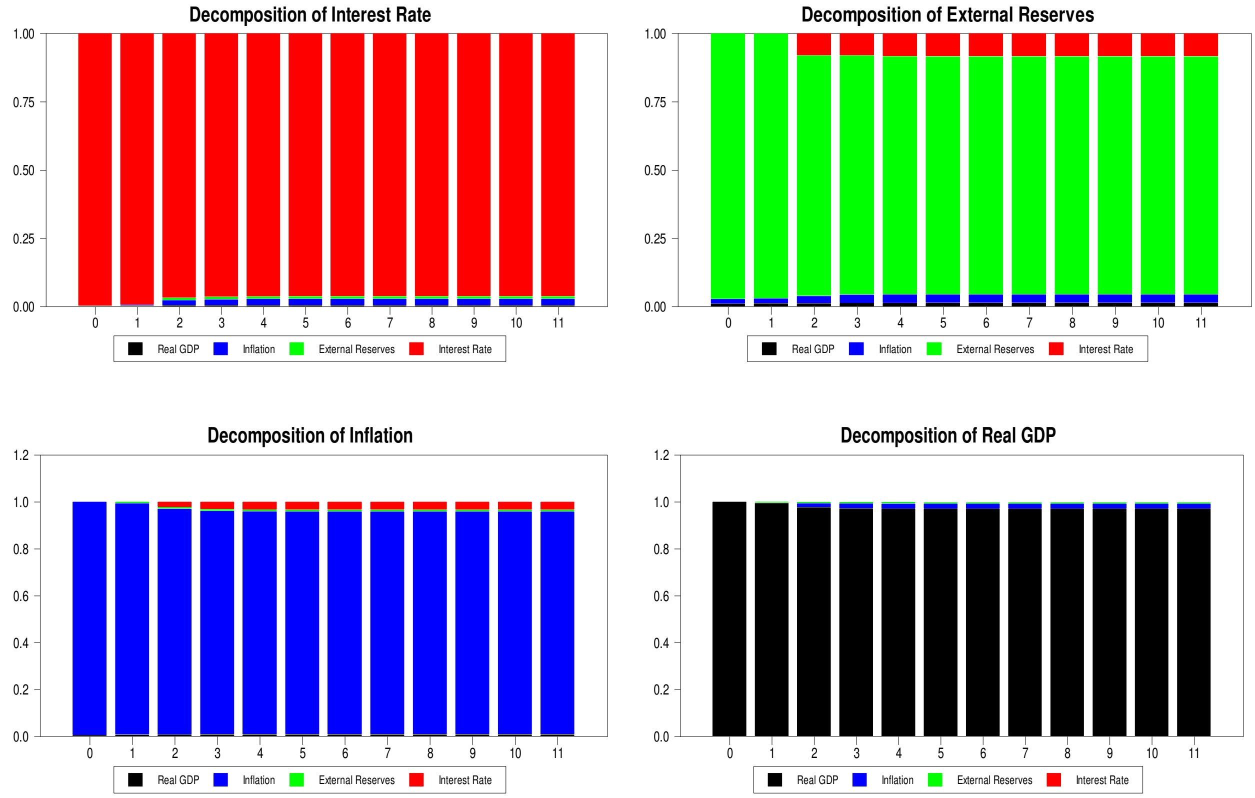
Table 1: **Decomposition of Forecast Error Variance (FEVD)**

Step	Std. Error	Real-GDP	CPI Inflation	FX Reserves	Interest Rate
Real-GDP (RGDP)					
1	0.180779	100.0000	0.0000	0.0000	0.0000
4	0.188687	97.1330	2.0920	0.6070	0.1680
8	0.189054	97.0440	2.1170	0.6150	0.2240
12	0.189055	97.0430	2.1180	0.6150	0.2240
Inflation Rate (CPI Inflation)					
1	5.461202	0.5040	99.4960	0.0000	0.0000
4	6.350799	0.7780	95.2380	0.7550	3.2290
8	6.359588	0.7770	95.0260	0.7600	3.4370
12	6.359779	0.7770	95.0230	0.7600	3.4390
Foreign-Exchange (External) Reserves (FXR)					
1	0.305509	0.9920	1.6970	97.3110	0.0000
4	0.324256	1.1940	3.1280	87.5630	8.1150
8	0.324980	1.2320	3.1340	87.1920	8.4430
12	0.324990	1.2320	3.1350	87.1890	8.4450
Interest Rate (INTRT)					
1	1.518372	0.0800	0.1080	0.0010	99.8110
4	1.544593	0.4210	2.1980	0.8750	96.5060
8	1.548579	0.4320	2.3830	0.8930	96.2920
12	1.548590	0.4320	2.3840	0.8930	96.2910

Note: The standard errors roughly indicate sampling uncertainty (Lütkephol, 2005).

The FEVD reveals the proportion of the movements in a series due to its own shocks versus shocks to the other variables. The variance decomposition technique can be quite useful a tool in examining the relationships among economic variables. The FEVD result presented in Table 1 shows the variance decompositions for the selected variables. The 3rd column of Table 1 contains the variance decompositions when output (RGDP) is the linear benchmark and it can be observed that CPI inflation rate variations contributed 2.092% to variation in RGDP in the 4th quarter and this increased slightly to 2.117% and 2.118% in the 8th and 12th periods. FX reserves contributed 0.607% to variation in output in the 4th quarter. In the case of interest rate it contributed 0.168% and 0.224% in the 4th and 8th quarters to variations in output respectively. When CPI inflation rate is the linear benchmark it accounts for 99.496%, 95.238%, 95.026% and 95.023% of its variations in the model corresponding to the 1st, 4th, 8th and 12th periods respectively. Interest rate however, contributed 3.229% and 3.437% to variations in inflation rate in the 4th and 8th periods respectively. At the 8th period horizon, 0.777% of the error in the forecast of CPI inflation is attributed to the RGDP. When interest rate is the linear benchmark, it accounts for 99.811%, 96.506% and 96.292% of its variations in the model corresponding to the relevant time horizon. It can be observed that the influence is decreasing with time. At the 8th period horizon, 0.432% of the error in the forecast of interest rate is attributed to the RGDP. Figure 1 presents the graphs of the decomposition of variances using Choleski shocks.

Figure 1: Forecast Error Variance Decomposition (FEVD) from VAR Model



4.2.2 TVP-VAR-with-SV Model Estimation and Discussion of Results

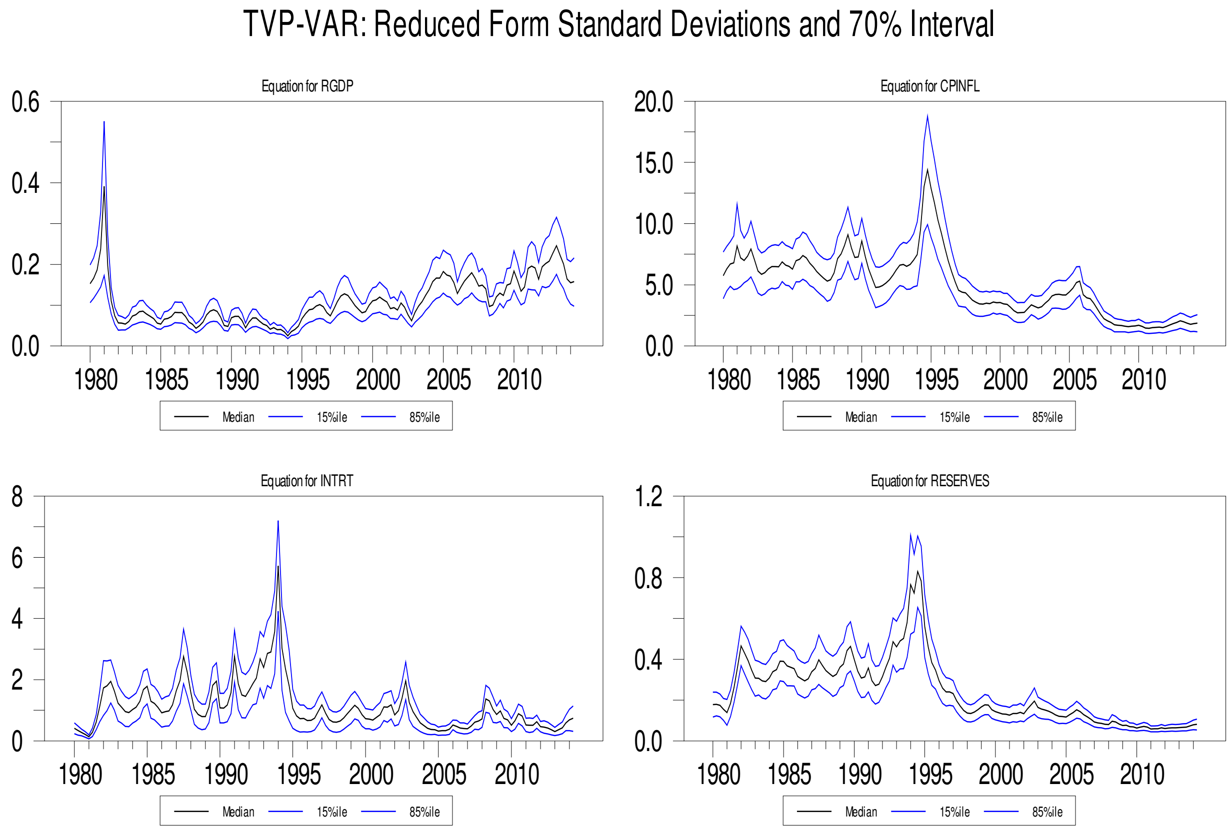
In estimating the TVP-VAR-with-SV model, the observation length used spans the period 1970Q1 to 2014Q2 with two lags. The model simulations are based on 10,000 iterations of the Gibbs sampler, discarding the first 2,000. The number of draws is 8,000 with burndraws equal to 5,000. In terms of setting the prior, following Primiceri (2005), we set a prior of normal distribution whose mean and variance are chosen based on the OLS estimates of a constant parameter-VAR model computed using the pre-sample period of 40 observations (training sample). Thus, the first 40 observations (1970Q1 to 1980Q1) are used to calibrate the prior distributions and data from 1980Q2 to 2014Q2 were used to estimate the model. Following Primiceri's (2005) strategy, we calculate the IRFs for a shock at time τ with response over any time period from τ to $\tau + n$ based on the parameters as they are at time τ[1].

On the exogenous shocks, we plot their standard deviations (σ_t) (that is the diagonal elements of $\mathbf{\Sigma}_t$ with the σ_t of the interest rate equation as our main focus). On the transmission mechanism, we analyse the mechanism through the IRFs. Based on our aim of analysing the evolving monetary policy, we mainly focus on the IRF of the variables in the non-policy block (e.g. inflation, FX reserves and real-GDP) to policy (i.e. interest-rate shock) block. Figure 2

[1]Del Negro and Primiceri (2015) have corrected the initial MCMC procedure and codes earlier presented in Primiceri (2005). The authors retain most of the procedures except that sampling of stochastic volatilities is now preceded by sampling of states for mixture components approximations to errors with log chi-squared distributions. We implement their updated procedure in our estimation of the TVP-VAR parameters.

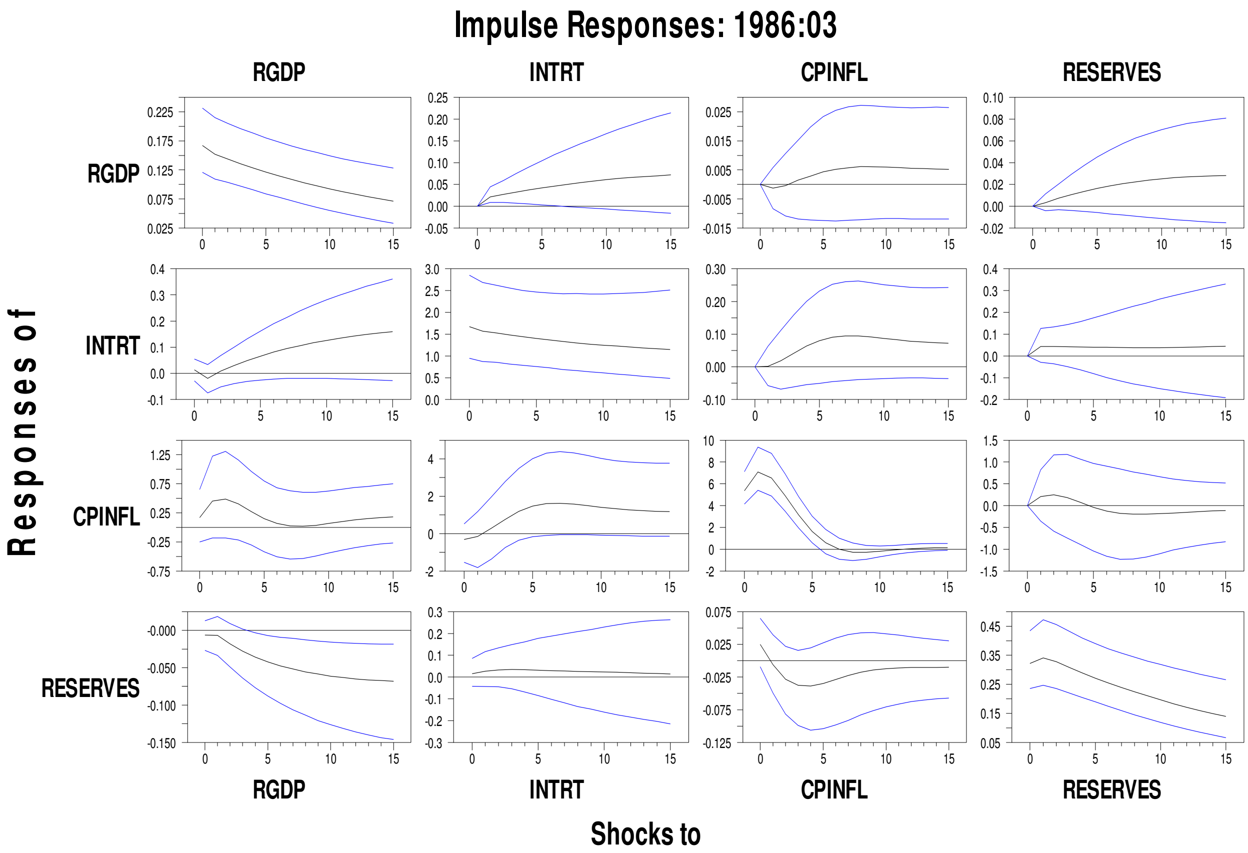
presents a plot of the posterior median and the 15th and 85th percentiles of the time-varying standard deviation. It indicates substantial variation in volatility associated with the equations for the four variables. The figure presents some striking features in the periods 1981–1982, 1994, 2004 and 2008–2009 which exhibits substantially higher variance of shocks with respect to the RGDP, inflation, interest rates and FX reserves equations respectively. For the interest-rate equation, significantly higher variances where observed in the periods 1987–1988, 1994, 2002–2003 and 2008–2009 and the volatility of the interest-rate equation was mostly higher in the pre-1994 period than in the post-1995 period.

Figure 2: Posterior Median & Percentiles of the Standard Deviation of Residuals



Results from Figure 2 above indicates evidence of parameter change as it relates to the error variances which were all changing with time for all the equations. It shows that exogenous shocks to RGDP, CPI inflation & interest rates and FX reserves played crucial roles. Additionally, other factors apart from monetary policy might be partly responsible for the rise in the variance of these macroeconomic variables. The effects of non-systematic monetary policy (monetary-policy shocks) is captured by the IRFs. Non-systematic monetary policy can result from the setting of monetary policy rates differently from the rule, or announcements by the CBN, among others. The change in the parameters identified above and whether it has macroeconomic impact are summarised in Figures 3, 4 & 5 respectively. The figures plot the IRFs of inflation, FX reserves and RGDP to a monetary-policy shock in three different dates of the sample. The figures represent pairwise relations among the variables as IRFs in different dates with the 15th and 85th percentiles. The dates chosen for the comparison are 1986Q3, 1999Q2 and 2009Q2. These represent periods of significant monetary policy changes by the CBN. The first period (i.e. 1986Q3) is associated with the implementation of the structural adjustment programme (SAP) in Nigeria that led to the deregulation of interest rates and devaluation of the currency, among others. The second period is associated with the return to democratic rule and the subsequent changes in monetary policy direction. The third period is associated with the global financial crisis and the country's banking crisis.

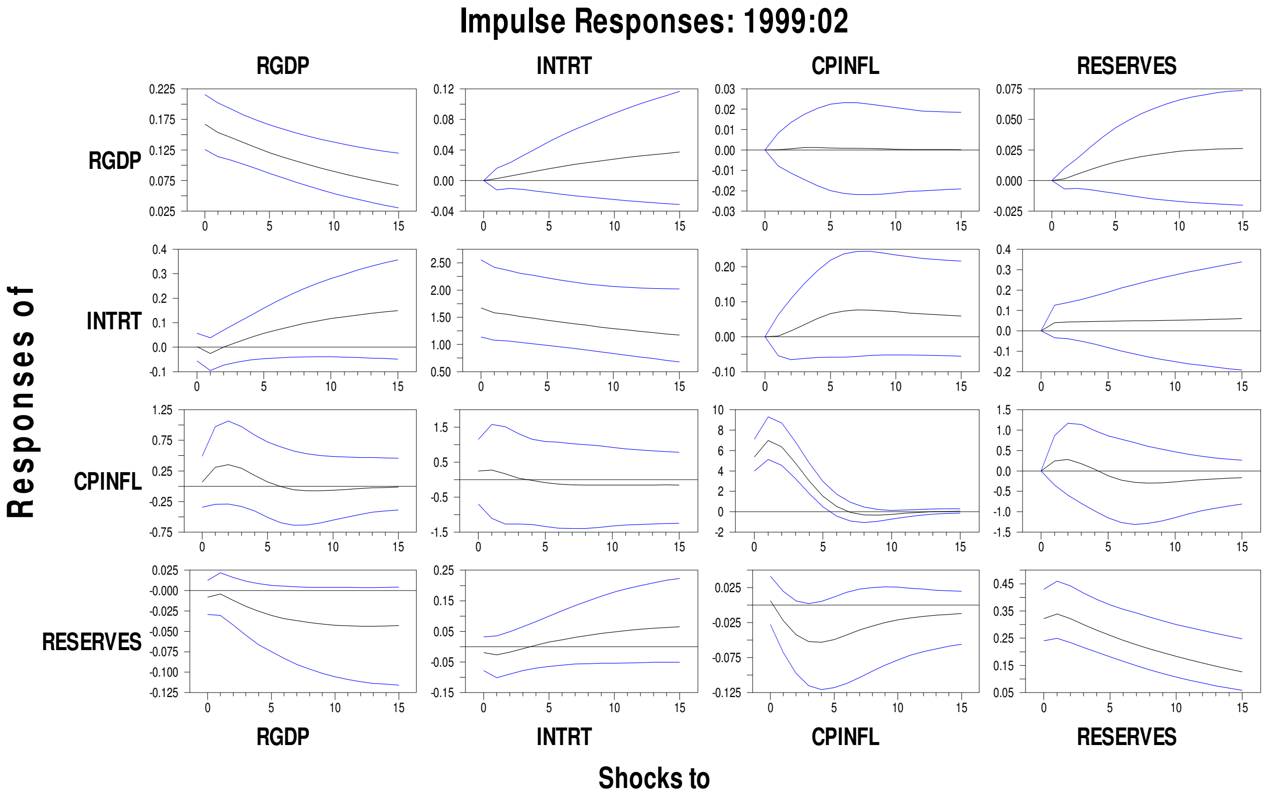
Figure 3: Impulse Responses of RGDP, FXR and Inflation to Monetary Shock



Based on the paper's objective, which borders on analysing the evolution of monetary policy, we focus mainly on IRFs to a monetary policy shock. Specifically, we calculate the effect of a shock of a given size and traced out its effect on other variables. Figures 3, 4 & 5 present estimates of the impulse response to RGDP, interest rate, CPI inflation and FX reserves for the three representative periods: 1986Q3, 1999Q2 and 2009Q2. The response of the RGDP to monetary policy shock is similar in the 1999Q2 and 2009Q2 periods but slightly different in the 1986Q3 period. The response of CPI inflation to monetary shock however, exhibit more interesting patterns when we compare the responses between the three periods. The point estimate of responses of inflation to monetary shock in 1986Q3 is quite different from the pattern observed in 1999Q2 indicating that monetary shocks are having more impact as we move across time. The positive hump shaped response of CPI inflation to a monetary policy shock (often referred to as a price puzzle) briefly appeared but vanished in the subsequent periods. In addition, it implies that a contractionary monetary policy shock does reduce inflation at both medium- and long-term horizons. Nakajima *et al.*, (2011) state that "a rise in inflation after a monetary tightening using VAR estimates is well known as the price puzzle" (see also Sims, 1992). The explanations above on the evolution of the impact of monetary policy shocks are all based on point estimates of the IRFs. The lines in blue colour are the measures of uncertainty associated with the point estimates (i.e. the 70% bands).

The response of FX reserves to monetary policy shock exhibit interesting patterns when we compare the responses between the three periods. The point estimate of responses of FX reserves to monetary shock in 1986Q3 is quite different with the pattern in 1999Q2 and slightly different from the response in 2009Q2. The RGDP shock seems to have more significant impact on Nigeria's FX reserves than either CPI inflation shock and interest rate shock in all the 1986Q3 period. These responses vary substantially between each other over time, indicating that the estimated coefficients show much time variation. Thus, one of our main findings from

Figure 4: Impulse Responses of RGDP, FXR and Inflation to Monetary Shock

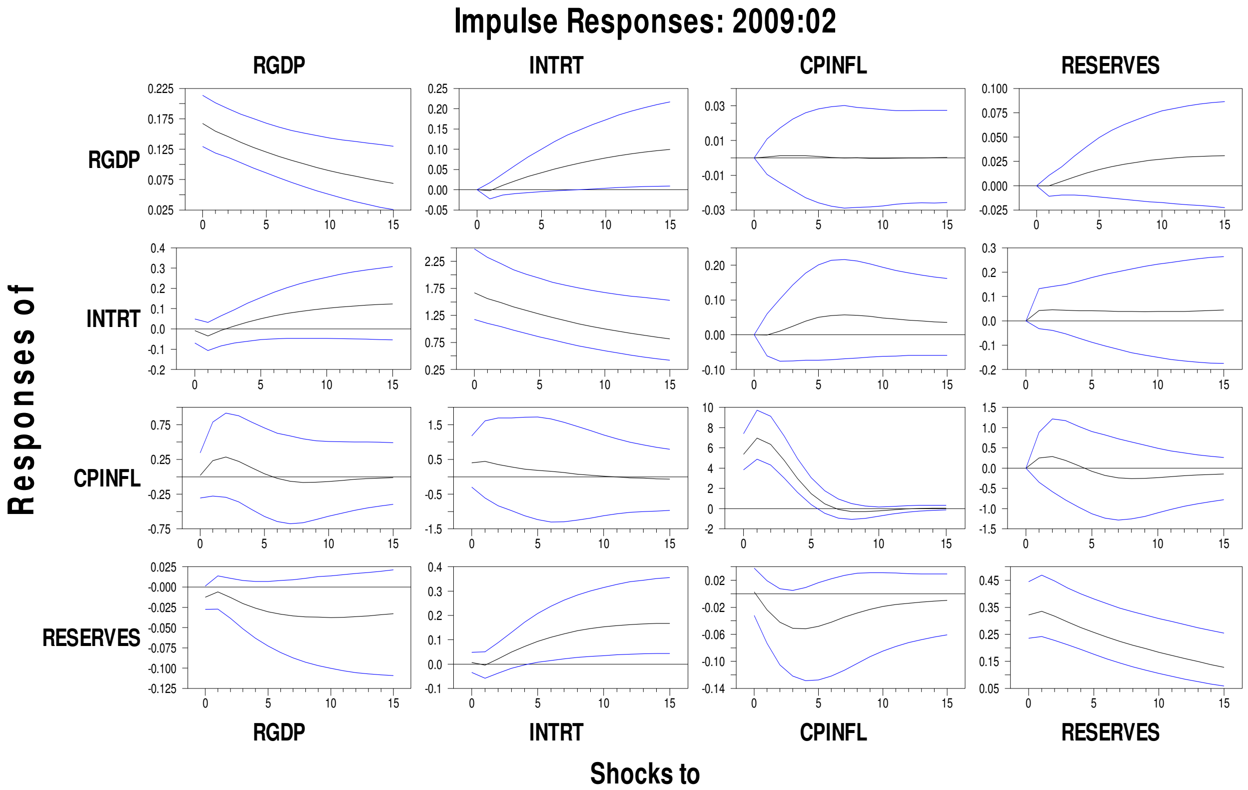


the above analysis is that there is a weak evidence of monetary policy playing a significant role in explaining the dynamics in RGDP because the impulse responses for the variable to a monetary policy shock do not change significantly over time. Some studies have raised concerns on the possibility that not all conditional mean parameters need to change together in a TVP-VAR model (see, Liu and Morley, 2014). That is some parameters may vary more frequently and strongly than others with some being approximately time-invariant which could make the estimation of TVP-VAR model to overstate variation in some parameters and understate variation in others. Based on empirical evidence, Liu and Morley (2014) find that "the restrictions on the structure of time-varying features of conditional mean parameters do not fundamentally change the volatility estimates, especially in terms of general changes over time, although they do influence the impulse response functions". This is consistent with Koop *et al.* (2009). Recent studies have recommended the idea of not forcing the non-policy parameters to change at the same time as those related to monetary policy. Figure A.2 present the trends of the TVP-VAR intercepts and medians for each equation.

5 Concluding Remarks

The analysis of the interactions between monetary policy and key macroeconomic and financial variables is crucial in enhancing economic stability and growth. That is why the TVP-VAR type models have recently attracted increased attention mainly as analytical tools used to examine changes in monetary and macroeconomic policies. Due to the usual caveats related to econometric specification, estimation and inference associated with constant-parameter-VAR model, the use of more sophisticated models have been suggested in order to minimise the effects of such restrictive assumptions. We employ TVP-VAR model because it incorporates stochastic volatility and time variation into VAR analysis and enables the shocks to vary over time as allowing the volatility of errors to be time-varying is now becoming increasingly important in empirical macroeconomics and many issues of macroeconomic policy now hinge on these

Figure 5: Impulse Responses of RGDP, ER and Inflation to Monetary Shock



dynamics. This paper examines the role of monetary policy in the dynamics of CPI inflation, FX reserves and RGDP in Nigeria using Bayesian methods in the estimation of TVP-VAR models. The main finding from the analysis is that there is a strong evidence of monetary policy playing a significant role in explaining the dynamics of inflation as the impulse responses for the variables to a monetary policy shock do change significantly over time. However, we observe that monetary policy shocks exert less significant influence than other exogenous non-policy shocks in explaining the dynamics in real-GDP and FX reserves. In addition, as for the FX reserves variable, it might be affected more by non-policy or other exogenous shocks, such as oil price shocks than monetary policy shocks. We also find that the transmission mechanism and the variance of the exogenous shocks for the Nigerian economy are time varying. Accordingly, we identify periods of significantly high volatility in the residuals of the TVP-VAR equations for each of the variables.

References

[1] Central Bank of Nigeria (2010) *Statistical Bulletin,* 50 Years Special Anniversary Edition, Abuja.

[2] Central Bank of Nigeria (2011) "Understanding Monetary Policy Series No. 1, What is Monetary Policy?"

[3] Central Bank of Nigeria (2015) "Quarterly Economic Report", Nigeria.

[4] Cogley, T. and Sargent, T. S. (2005) "Drifts and Volatilities: Monetary Policies and Outcomes in the Post WWII US", *Review of Economic Dynamics*, **8**, 262–302.

[5] D'Agostino, A., Gambetti, L. and Giannone, D. (2010) "Macroeconomic Forecasting and Structural Change", *ECB Working Paper*, No. 1167, European Central Bank.

[6] Del Negro, M. and Primiceri, G. E. (2015) "Time Varying Structural Vector Autoregressions and Monetary Policy: A corrigendum", Manuscript.

[7] Del Negro, M. and Primiceri, G. E. (2015) "Time varying structural vector autoregressions and monetary policy: appendix to corrigendum", Manuscript.

[8] Doguwa, S. I. and Essien, S. N. (2013) "The Role of Central Bank of Nigeria's Analytical Balance Sheet and Monetary Survey in Monetary Policy Implementation", *CBN Journal of Applied Statistics*, **4**, 119–138.

[9] Gerlach, R., Carter, C. and Kohn, R. (2000) "Efficient Bayesian Inference for Dynamic Mixture Models", *Journal of the American Statistical Association*, **95**, 451, 819–828.

[10] Giordani, P. and Kohn, R. (2008) "Efficient Bayesian Inference for Multiple Change-Point and Mixture Innovation Models", *Journal of Business and Economic Statistics*, **26**, 66–77.

[11] Hatemi-J, A. (2014) "Asymmetric Generalised Impulse Responses with an Application in Finance", *Economic Modelling*, **36**, 18–22.

[12] Josfidis, K., Allegret, J-P., Gimet, C., and Pucar, E. B. (2014) "Macroeconomic Policy Response to Financial Crises in Emerging European Economies" *Economic Modelling*, **36**, 577–591.

[13] Joyce, M., Tong, M. and Woods, R. (2011). "The United Kingdom's Quantitative Easing Policy: Design, Operation and Impact", Quarterly Bulletin, 2011 Q3.

[14] Joyce, M., Miles, D. Scott, A. and Vayanos, D. (2012) "Quantitative Easing and Unconventional Monetary Policy–An Introduction", *The Economic Journal*, **122**, F271–F288.

[15] Kapetanios, G., Mumtaz, H., Stevens, I. and Theodoridis, K. (2012) "Assessing the Economy-Wide Effects of Quantitative Easing", *The Economic Journal*, **122**, F316–F347.

[16] Koop, G., Pesaran, H. and Potter, S. M. (1996) "Impulse Response Analysis in Nonlinear Multivariate Models", *Journal of Econometrics*, **74**, 119–147.

[17] Koop, G., Leon-Gonzalez, R. and Strachan, R. W. (2009) "On the Evolution of the Monetary Policy Transmission Mechanism", *Journal of Economic Dynamics and Control*, **33**, 997–1017.

[18] Koop, G., and Potter, S. M. (2011) "Time Varying VARs with Inequality Restrictions", *Journal of Economic Dynamics and Control* **35**, 1126–1138.

[19] Liu, Y. and Morley, J. (2014) "Structural Evolution of the Postwar U.S. Economy", *Australian School of Business Working Paper No. 2013 ECON15A*.

[20] Lütkephol, H. (2005) *"New Introduction to Multiple Time Series Analysis",* Springer, Berlin.

[21] Nakajima, J., Kasuya, M. and Watanabe, T. (2011) "Bayesian Analysis of Time-Varying Parameter Vector Autoregressive Model for the Japanese Economy and Monetary Policy", *Journal of the Japanese and International Economies*, **25**, 225–245.

[22] Nakajima, J. (2011) "Time-Varying Parameter VAR Model with Stochastic Volatility: An Overview of Methodology and Empirical Applications", *Monetary and Economic Studies*, 107–142.

[23] National Bureau of Statistics (NBS) (2014) Measuring Better: Presentation of Preliminary Results of the Rebased Nominal Gross Domestic Product (GDP) Estimates for Nigeria 2010 to 2013, April, 2014.

[24] Olowofeso, O. E., Bada, A. S., Bassey, K. J. and Dzan, K. S. (2014) "The Balance Sheet Channel of Monetary Policy Transmission: Evidence from Nigeria", *CBN Journal of Applied Statistics*, **5**, 95–116.

[25] Primiceri, G. E. (2005) "Time Varying Structural Vector Autoregressions and Monetary Policy", *The Review of Economics and Statistics*, **72**, 821–852.

[26] Sims, C. A. (1980) "Macroeconomics and Reality, *Econometrica,* **48**, 1–48.

[27] Sims, C. A. (1988) "Bayesian Skepticism on Unit Root Econometrics, *Journal of Economic Dynamics and Control,* **12**, 463–474.

[28] Sims, C. A. (1991) "Understanding Unit Rooters: A Helicopter Tour, *Econometrica,* **59**, 1591–1599.

[29] Sims, C. A. (1992) "Interpreting Macroeconomic Time Series Facts: The Effects of Monetary Policy, *European Economic Review,* **36**, 975–1011.

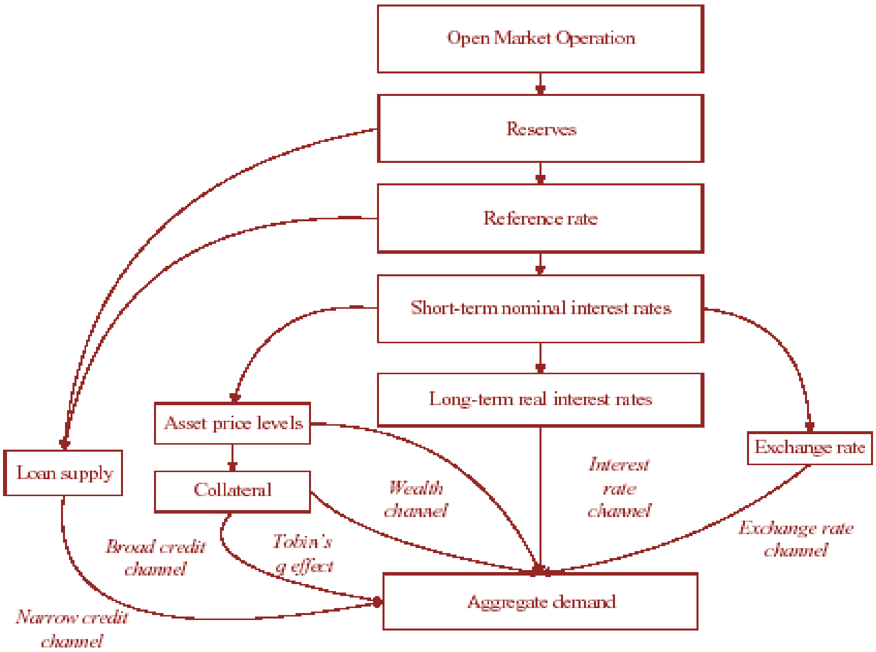
[30] Teräsvirta, T., Tjostheim, D., and Granger, C. W. J., 2010. "Modelling Nonlinear Economic Time Series", Oxford University Press.

[31] Ueda, K. (2013) "Response of Asset Prices to Monetary Policy Under Abenomics", *Asian Economic Policy Review*, **8**, 252–269.

[32] Uhlig, H. (1997) "Bayesian Vector Autoregressions with Stochastic Volatility", *Econometrica,* **65**(1), 59–73.

6 Appendix

Figure A.1: Balance Sheet Channel of Monetary Policy Transmission in Nigeria



Source: Central Bank of Nigeria (2011)

Figure A.2: TVP-VAR Intercepts and Medians for Each Equation