Global Journal of HUMAN-SOCIAL SCIENCE: E
Economics
Volume 19 Issue 6 Version 1.0 Year 2019
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-460x & Print ISSN: 0975-587X

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By Alabi Nurudeen Olawale & Bada Olatunbosun

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GJHSS-E Classification: FOR Code: 1149999

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Abstract- This paper is an investigation of causal relationships that exist between macroeconomic variables in Nigeria context. These variables are interest rate, inflation rate, exchange rate, real gross domestic product, and unemployment rate. Often, a variable can better be forecasted by introducing past and current values of some other variables in the ARMA model or its AR approximation. We achieved this by employing an augmented VAR approach, such as the procedure proposed by Toda-Yamamoto. This current work included a unit-root test with trend break functions without a priori information. Specifically, we employed the extended Augmented Dickey-Fuller test through innovational outlier and additive outlier models. The truncation parameter was selected using the t-sig and F-sig general to specific recursive techniques. Unknown breakpoints were observed, which indicates a strong connection with the data. Furthermore, the Toda-Yamamoto procedure result was confirmed using a bounds test to check cointegration amongst these macroeconomic variables. Univariate and multivariate causality was established amongst them. Specifically, pairwise unilateral causality was revealed amongst the macroeconomic variables except for inflation rate and real GDP. These two macroeconomic variables granger cause each other. Surprisingly, interest rate, exchange rate, inflation rate, and unemployment rate do not granger cause real GDP either individually or jointly. In the interest rate VAR, all other variables granger cause interest rate individually and jointly. Conversely, only real GDP granger causes inflation rate. The unemployment rate can better be forecasted using the past and current values of the inflation rate, exchange rate, and real GDP.

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I. Introduction

The concept of Granger Causality has been extensively studied in the fields of finance and economics in recent times. The term is used to describe how possible it is to predict the future values of a variable using the past values of that variable and another variable in bivariate and multivariate settings.

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Several methods have been proposed over the years. Granger (1969) was the first to present this type of relationship between two variables. However, this method suffered serious limitations, especially when any of the time series is non-stationary. This is because when some of the series are non-stationary, the Wald test on Granger causality with linear restrictions on the parameters of the vector autoregressive model (VAR) does not follow its usual asymptotic χ^2- distribution under the null hypothesis. The presence of latent parameters which distort the test statistic's asymptotic distribution is produced. As a result of this limitation, modified tests have been proposed. Prominent are Toda and Yamamoto (1995), Dolado and Lütkepohl (1996), Saikkonen and Lütkepohl (1996) and more recently, Bauer and Maynard (2012). Toda-Yamamoto (1995) method involves determining the lag length p using the usual lag selection procedures and estimating a $(p+d_{max})$th order VAR where d_{max} is the maximum order of integration of the model. Furthermore, the coefficients of the d_{max} lagged vectors in the VAR are ignored. Dolado and Lütkepohl (1996) proposed a simple method which under general conditions guarantees that Wald test follows the asymptotic χ^2 – distribution by fitting a VAR$(p+1)$ to a VAR(p) data and perform a Wald test on the coefficients of the first p lags. Saikkonen and Lütkepohl (1996) estimated cointegrated systems through autoregressive approximation by deriving the asymptotic properties of the estimated coefficients of the error correction model (ECM) and the pure VAR model under the assumption that the order of the autoregressive model tends to infinity with increasing sample size. Bauer and Maynard (2012) proposed a highly robust Granger causality test that accommodates VAR models with unknown integration orders by employing the surplus lag approach to an infinite order VARX framework. These modifications to the standard approach proposed by Granger in 1969 are needed to ensure that the Wald test statistic follows the asymptotic χ^2 – distribution under the null hypothesis.

II. Some Related Works

Several studies have looked at the causality existing between macroeconomic variables around the world. Most of these works focus on the usual Wald test mainly because the macroeconomic variables involved are of the same order of integration. For instance, Gocmen (2016) investigated the causality existing between money supply and prices in the Turkish economy. This study identified stronger bivariate causality and multivariate from inflation rate to the money supply. Umaru & Zubairu (2012) established a unilateral causality from GDP to inflation rate using data between 1970 and 2010 in Nigeria. The study emphasized that the two major macroeconomic variables are I (1) hence, the use of the usual Augmented Dickey-Fuller and Phillips-Peron unit-root tests. Pakistan is one of the ASEAN countries experiencing a surge in the inflation rate. Nawaz et *al.* (2017) investigated the correlation and causality between inflation, money supply, government expenditure, government revenue, foreign direct investment, gross domestic product and interest rate in Pakistan during the period 1990:2012. The study concluded that money supply and balance of trade causes inflation rate. Conversely, interest rate do not granger cause inflation rate during the review period. Similarly, Khalid (2005) analyzed the causality between economic growth, inflation rate, and several monetary policy indicators in Pakistan using quarterly data from 1960 to 2005. The study reveals both unilateral and bilateral causality amongst these variables. Particularly, no causality in neither direction could be established between the inflation rate and exchange rate. In Nigeria, Odo et *al.* (2017) while studying the long-run comovement amongst five macroeconomic variables, carried out a test of granger causality and found that total government expenditure as a percentage of gdp causes unemployment rate. Other variables in the study, such as inflation rate, broad money supply (M2) as percentage of GDP and total government expenditure do not have any causality amongst them. The conclusion is quite contradictory to that drawn in the cointegration test. It was found that these macroeconomic variables move together in the long-run. But theoretically, if two more variables are cointegrated, then there must exist causality either unilaterally or bilaterally amongst them. In another work by Belka et *al.* (2004) which involves the study of exogeneity of volatility concerning the real economy using the exchange rate and interest rate in Argentina and Brazil, it was revealed that causality existed from employment rate to volatility of Argentina nominal interest. Similarly, unidirectional causality existed from the nominal exchange rate of US$/Euro to volatility of nominal rate of US$ to Euro. Furthermore, Brazilian nominal exchange rates to Euro cause volatility of the Brazilian nominal exchange rate to Euro. In another related work by Abeng and Alehile (2012), bidirectional and unidirectional causality was established amongst several macroeconomic variables such as real output, interest rate, exchange rate, inflation rate and crude oil price in Nigeria. This study also employed the Wald test since all the variables are of the same order, i.e. I (1). Ojo & Alege (2014) conducted panel granger causality test as part of their study on the exchange fluctuation and macroeconomic performance in Nigeria and 39 other sub-Saharan African countries over 13 years. The macroeconomic variables included in the study are real gross domestic product, national exchange rate per US$, consumer price index, degree of openness, interest rate, government expenditure, and foreign direct investment. The study reveals no causality between the national exchange rate and real gross domestic product; government expenditure and national exchange rate; foreign direct investment and national exchange rate. Conversely, there exist bidirectional causality between the degree of openness and national exchange rate; consumer price index and national exchange rate; interest rate and national exchange rate in these sub-Saharan African countries. Olusanya & Akinade (2012) employed the usual Wald test to examine the causality between economic growth (proxy by GDP) and a major macroeconomic indicator such as money supply during the Pre-Deregulated and Post-Deregulated Nigerian economy. Essentially, the Pre- and Post-Deregulated periods are 1970:1985 and 1986:2009 periods, respectively. Their findings show that there exists causality from economic growth to money supply but not vice versa during the Pre-Deregulation era. On the other hand, no causality was found between these two variables during the Post-Deregulation era. Sulaiman & Migiro (2014) in their study were able to show that there is unidirectional causality from the monetary policy rate (MPR) to gross domestic product (GDP); from exchange rate to GDP; from interest rate to GDP but not vice versa. However, no causality could be established between cash reserve ratio (CRR) and GDP; money supply and GDP.

We observed that in all these earlier works, the macroeconomic variables' order of integration were based on regular unit-root tests. Rather than using tests such as Augmented Dickey-Fuller test, Phillips-Perron (PP) test and other regular tests, this current study involves unit-root tests with allowance for a shift in the intercept of the trend function and slope since most macroeconomic time series are interpreted as stationary around a deterministic trend function. We employed the extended Augmented Dickey-Fuller test through innovational outlier and additive outlier models as proposed by Perron (1989, 1997).

III. Methodology, Analysis and Results

The monthly data used in this study is a secondary data extracted from the Central Bank of Nigeria between 2006 and 2018. The three monetary policy variables involved in the vector autoregressive (VAR) model comprise *interest rate* (*ir*) (proxy by Treasury bill rate), *inflation rate (inf)* and *exchange rate (ex)*. Also, a real gross domestic product (*rgdp*) was used as the measure of the Domestic Output and lastly unemployment rate (*um*). Since the series have different frequencies, particularly *real gdp,* which is a quarterly data, we converted it to monthly series without loss of statistical properties using the cubic low to high-frequency conversion method. Furthermore, we transformed the original data into the natural log to ensure that the normality assumptions in the error term in the VAR model can be sustained.

a) *Toda-Yamamoto Augmented VAR Approach*

Toda and Yamamoto (1995) proposed a modified method which allows the application of the lag selection procedure to integrated or cointegrated VAR and satisfying the asymptotic theory as long as the order of integration does not exceed the true lag length of the model. This method involves determining the lag length p using the usual lag selection procedures and estimating a $(p+d_{max})$th order VAR where d_{max} is the maximum order of integration of the model. Furthermore, the coefficients of the d_{max} lagged vectors in the VAR are restricted to zero in the linear model. Theoretically, if two or more series are cointegrated, then there will exist causality between them but not conversely. We express the vector autoregressive VAR models under Toda Yamamoto as follow:

$$um_t = \alpha_0 + \left[\sum_{i=1}^{p}\theta_{it}um_{t-i} + \sum_{i=p+1}^{d_{\max}}\theta_{2t}um_{t-i}\right] + \left[\sum_{i=1}^{p}\beta_{it}rgdp_{t-i} + \sum_{i=p+1}^{d_{\max}}\beta_{2t}rgdp_{t-i}\right] + \left[\sum_{i=1}^{p}\omega_{1t}\inf_{t-i} + \sum_{i=p+1}^{d_{\max}}\omega_{2t}\inf_{t-i}\right]$$
$$+\left[\sum_{i=1}^{p}\pi_{1t}ir_{t-i} + \sum_{i=p+1}^{d_{\max}}\pi_{2t}ir_{t-i}\right] + \left[\sum_{i=1}^{p}\phi_{1t}ex_{t-i} + \sum_{i=p+1}^{d_{\max}}\phi_{2t}ex_{t-i}\right] + \mu_{1t}$$

$$rgdp_t = \psi_0 + \left[\sum_{i=1}^{p}\upsilon_{it}rgdp_{t-i} + \sum_{i=p+1}^{d_{\max}}\upsilon_{2t}rgdp_{t-i}\right] + \left[\sum_{i=1}^{p}\tau_{it}um_{t-i} + \sum_{i=p+1}^{d_{\max}}\tau_{2t}um_{t-i}\right] + \left[\sum_{i=1}^{p}\delta_{1t}\inf_{t-i} + \sum_{i=p+1}^{d_{\max}}\delta_{2t}\inf_{t-i}\right]$$
$$+\left[\sum_{i=1}^{p}\rho_{1t}ir_{t-i} + \sum_{i=p+1}^{d_{\max}}\rho_{2t}ir_{t-i}\right] + \left[\sum_{i=1}^{p}\eta_{1t}ex_{t-i} + \sum_{i=p+1}^{d_{\max}}\eta_{2t}ex_{t-i}\right] + \mu_{2t}$$

$$\inf_t = \vartheta_0 + \left[\sum_{i=1}^{p}\varpi_{1t}\inf_{t-i} + \sum_{i=p+1}^{d_{\max}}\varpi_{2t}\inf_{t-i}\right] + \left[\sum_{i=1}^{p}\xi_{it}um_{t-i} + \sum_{i=p+1}^{d_{\max}}\xi_{2t}um_{t-i}\right] + \left[\sum_{i=1}^{p}\gamma_{it}rgdp_{t-i} + \sum_{i=p+1}^{d_{\max}}\gamma_{2t}rgdp_{t-i}\right]$$
$$+\left[\sum_{i=1}^{p}\sigma_{1t}ir_{t-i} + \sum_{i=p+1}^{d_{\max}}\sigma_{2t}ir_{t-i}\right] + \left[\sum_{i=1}^{p}\phi_{1t}ex_{t-i} + \sum_{i=p+1}^{d_{\max}}\phi_{2t}ex_{t-i}\right] + \mu_{3t}$$

$$ir_t = \alpha_0 + + \left[\sum_{i=1}^{p}\zeta_{1t}ir_{t-i} + \sum_{i=p+1}^{d_{\max}}\zeta_{2t}ir_{t-i}\right] + \left[\sum_{i=1}^{p}\mu_{it}\inf_{t-i} + \sum_{i=p+1}^{d_{\max}}\mu_{2t}\inf_{t-i}\right] + \left[\sum_{i=1}^{p}o_{it}ex_{t-i} + \sum_{i=p+1}^{d_{\max}}o_{2t}ex_{t-i}\right]$$
$$+\left[\sum_{i=1}^{p}\iota_{1t}rgdp_{t-i} + \sum_{i=p+1}^{d_{\max}}\iota_{2t}rgdp_{t-i}\right] + \left[\sum_{i=1}^{p}\vartheta_{1t}um_{t-i} + \sum_{i=p+1}^{d_{\max}}\vartheta_{2t}um_{t-i}\right] + \mu_{4t}$$

$$ex_t = \chi_0 + \left[\sum_{i=1}^{p}\mathrm{A}_{1t}ex_{t-i} + \sum_{i=p+1}^{d_{\max}}\mathrm{A}_{2t}ex_{t-i}\right] + \left[\sum_{i=1}^{p}\Phi_{it}um_{t-i} + \sum_{i=p+1}^{d_{\max}}\Phi_{2t}um_{t-i}\right] + \left[\sum_{i=1}^{p}\Psi_{it}rgdp_{t-i} + \sum_{i=p+1}^{d_{\max}}\Psi_{2t}rgdp_{t-i}\right]$$
$$+\left[\sum_{i=1}^{p}\Omega_{1t}\inf_{t-i} + \sum_{i=p+1}^{d_{\max}}\Omega_{2t}\inf_{t-i}\right] + \left[\sum_{i=1}^{p}\Lambda_{1t}ir_{t-i} + \sum_{i=p+1}^{d_{\max}}\Lambda_{2t}ir_{t-i}\right] + \mu_{5t}$$

Where p is the optimal lag on the initial VAR and d_{max} is the maximal order of integration on the five macroeconomic variables. We assumed that the variables could be approximated by the natural log-linear VAR (p) model to sustain the normality assumption. Firstly, we conducted tests for the presence of unit-root on the three macroeconomic variables. Depending on the order of integration, we select the maximum order, i.e. d_{max} and specify an unrestricted VAR (p) model using the lag length criteria LR, FPE, AIC, SIC and HQIC. Stability checks were conducted on the adjusted VAR ($p+d_{max}$) model through the autocorrelation LM test on the VAR residuals.

If two or more of the time series are of the same integration order, a test to see if they are cointegrated, using ARDL modeling approach, for example, is needed. We take the preferred VAR model and d_{max} additional lags of each of the variables into each of the equations. Conclusions about the existence of long-run form (i.e., cointegration) do not affect this step but provide cross-check on the validity of our results at the end of the analysis. Test of Granger non-causality by testing the hypothesis that the coefficients of (only) the first p lagged values of *real gdp, inflation rate, interest rate,* and *exchange rate* are zero in the unemployment rate equation, using a standard Wald test. This test is repeated for the coefficients of the p lagged values of the monetary policy indicators and *real gdp* variable equations. The coefficients for the remaining d_{max} lags were excluded when performing the Wald tests (i.e., they enter the models as deterministic terms alongside the intercept). This is to ensure that the Wald test statistics follow asymptotic chi-square distribution with p degrees of freedom, under the null hypothesis. Rejection of the null implies support of the presence of Granger causality. Finally, we revisit the conclusion made during the test of cointegration. Theoretically, Granger causality, either unidirectional or bidirectional, will exist between two or more cointegrated time series but not vice versa.

b) *Unit-root tests using the Innovational Outlier and Additive Outlier Models*

We begin the analysis by studying the stationarity of each of the series by conducting unit-root tests. An extended Augmented Dickey-Fuller test with innovational outlier and additive outlier breakpoints as proposed by Perron (1989, 1997) were employed (Models 1, 2 & 3). According to Zivot & Andrews (1992), Lumsdaine & Papell (1997) & Perron (1989, 1997), if allowance is made for a shift in the intercept of the trend function and slope, most macroeconomic time series are interpreted as stationary around a deterministic trend function. We considered the following three models at levels with dummy variables for different intercepts and slopes. The Model 1 involves including the dummy variable for a change in the intercept of the trend function steadily in a way that relies on the correlation function and the innovation (i.e., noise) function (Perron, 1997). The dummy variables are presumed to be unknown rather than known ex-ante.

$$\Delta y_t = \mu + \theta DU_t + \beta t + \phi D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} z_i \Delta y_{t-i} + e_t$$

Model 1

$$\Delta y_t = \mu + \theta DU_t + \beta t + \omega DT_t + \phi D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} z_i \Delta y_{t-i} + e_t$$

Model 2

$$\Delta y_t = \mu + \theta DU_t + \beta t + \omega DT_t^* + \tilde{y}$$

Model 3

where

$$\tilde{y} = \alpha \tilde{y}_{t-1} + \sum_{i=1}^{k} z_i \Delta \tilde{y}_{t-i} + e_t$$

These models were estimated using the Ordinary Least Squares (OLS). The indicator functions $1(\cdot)$ are expressed as $DU_t = 1(t > T_b)$, $D(T_b)_t = 1(t = T_b + 1)$, $DT_t = 1(t > T_b + 1)t$ and $DT^*{}_t = 1(t > T_b)(t - T_b)$. We test the null hypothesis that α = 1 using the t-statistic $t_{\hat{\alpha}}(T_b, k)$, where k is the truncation lag parameter which is also unknown. Models 1 and 2 are referred to as the *innovational outlier models* (i.e., IO1 and IO2) respectively. Model 3 is called the *Additive model* (i.e., AO) because a rapidly change in the slope is allowed but the two fragments of the trend function are joined at the breakpoint. According to Perron (1989 & 1997), the breakpoint T_b may be chosen such that $t_{\hat{\alpha}}(T_b, k)$ is minimized. The minimized t-statistic is expressed as:

$t^*_{\hat{\alpha}} = \min_{T_b \in (k+1,T)} t_{\hat{\alpha}}(T_b, k)$ The break point was selected in a manner to maximize the t-statistic $t_{\hat{\omega}}$ on the shift in slope. Here, the test statistic for testing the null hypothesis α = 1 are $t^{*}{}_{\alpha,|\hat{\theta}|} = (T_b^*, k)$ for model 1 and $t^{*}{}_{\alpha,|\hat{\omega}|} = (T_b^*, k)$ for models 2 and 3, where T_b^* is such that $t^*_{\hat{\omega}}(T_b^*) = \max_{T_b \in (k+1,T)} | t_{\hat{\omega}}(T_b, k) |$ and $t^*_{\hat{\theta}}(T_b^*) = \max_{T_b \in (k+1,T)} | t_{\hat{\theta}}(T_b, k) |$. T_b was selected by allowing this point to correlate with the data as much as possible although with some loss in power. This was done by imposing no restrictions on the sign of the change. The truncation parameter *k** was selected using the *t*-sig and *F*-sig general to specific recursive procedures as proposed by Perron (1989). These procedures are particularly better than information criteria such as Akaike Information Criterion and Bayesian Information Criterion due to their size stability and better power (Perron, 1989).

Table 1: Summary of Unit-Root Test results using Models 1, 2 and 3.

Variable	Model	ADF test@	k max	k^*	Breakpoint	t-statistic	t-sig p-value	F-sig p-value	Remark
um	IO1	1st Difference	12	12	2016:12	-4.7523	……….	0.0637	I(1)
rgdp	AO	1st Difference	13	12	2007:07	-4.6286	……….	0.0132	I(1)
inf	AO	Level	13	13	2011:10	-5.2002	0.0177	……….	I(0)
ir	IO2	Level	5	1	2015:09	-4.8494	0.011	……….	I(0)
ex	IO1	Level	5	1	2015:12	-5.0324	0.0286	……….	I(0)

Source: Authors personal computation

The results of unit-root test reveal that *unemployment rate,* and *real gdp* are stationary of order one under the Innovational Outlier Model 1 and Additive Outlier Model respectively. The truncation lag lengths of *k** = 12 were selected using the *F*-sig approach. The *p*-value for the *real gdp* unit-root test is lower than that of the *unemployment rate* unit-root test. This is an indication that the Additive Outlier Model has more power than the Innovational Outlier Model 1 on these series. The remaining series, i.e. *inflation rate*, *interest rate,* and *exchange rate* are stationary at level under Additive Outlier model, Innovational Outlier Models 2, and 3 respectively. The *k** = 13 for *inflation rate* and *k** = 1 for *interest rate* and *exchange rate* were chosen using the *t*-sig recursive tehnique. The *k* max was chosen arbitrarily avoiding the problems of multicollinearity amongst the variables and loss of power usually associated with high values of *k* max. This quantity was 13 lags (for *real gdp* and *inflation rate*) and 5 lags (for both interest rate and exchange rate). Only the *unemployment rate* has a binding *k* max at 12 lags. The breakpoint dates correspond to significant periods of global economic and Nigerian government policy change shocks. The logarithms of the macroeconomic variables are as shown in Fig. 1 below. The breakpoints are selected to maximize the *t*-statistics (Table 1).

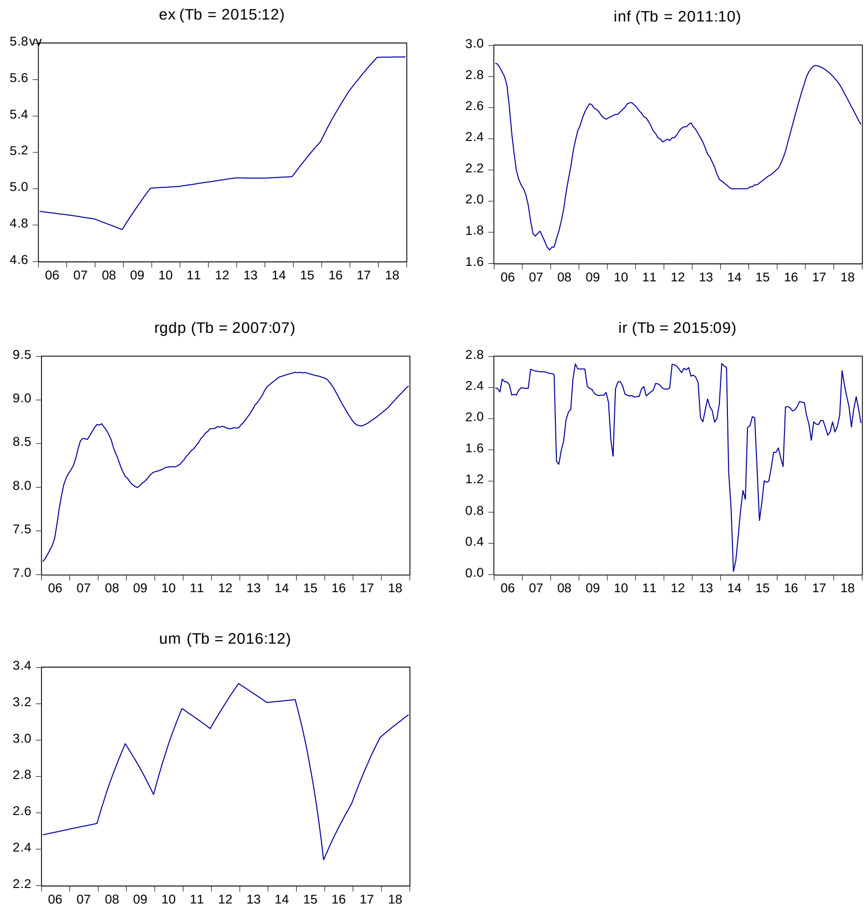


Fig. 1: Log exchange rate, log inflation rate, log real gdp, log interest rate and log unemployment rate for Nigeria between 2006 and 2018

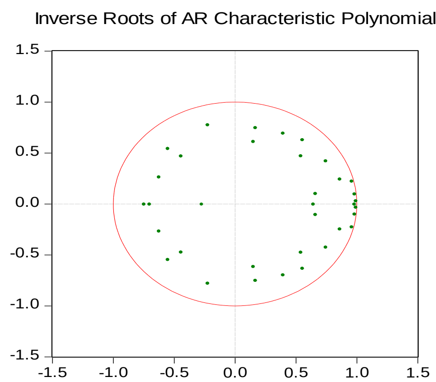
Firstly, there was a global financial crisis in 2007 when major financial institutions in the United States collapsed. The effect of the global financial crash was observed in Nigeria's *real gdp* in July of 2007. Secondly, Nigeria is known for its inflation targeting monetary policy. Under this policy, the Central Bank of Nigeria (CBN) uses the monetary policy rate (MPR) and cash reserve ratio (CRR) to control rate of inflation in the economy. Hence, the breakpoint of 2011:10 in inflation rate series is a consequence of the upward review of CBN's Minimum Rediscount Rate (MRR) from 9.25 percent to 12 percent in October 2011. Furthermore, in 2015, the Central Bank of Nigeria reduced the Monetary Policy Rate (MPR) from 13 percent to 11 per cent culminating into the September 2015 breakpoint date in the *interest rate* series. Thirdly, in October 2015, JP Morgan expelled Nigeria from its Global Bond Index-Emerging Market (GBI-EM). GBI-EM is an index which tracks local currency bonds by emerging market governments. This decision led to the efflux of foreign investors holdings in Nigeria bonds. The effect was revealed in a breakpoint of 2015:12 in the *exchange rate* series. Finally, there is a strong connection between economic growth and unemployment rate. According to the United Nations Development Programme 2016 annual report on Nigeria, the country's economy witnessed contraction (recession) for the first time in several decades. This resulted in an escalation of *unemployment rate,* especially amongst the youth, which led to the introduction of several government youth empowerment programmes to reverse the trend. The contraction was captured by the December 2016 breakpoint observed in the *unemployment rate* series. Thus, by introducing trend break functions in the unit-root tests without a priori information, we have been able to establish a good connection between the various breakpoints and the macroeconomic series. This is in line with previous works by Perron (1997), Zivot & Andrews (1992), Banerjee et *al*. (1992), Lumsdaine & Papell (1997), Ling et *al*. (2013), Arestis & Mariscal (2000), Basher & Westerlund (2008), Chiang & Ping (2008), Narayan & Smyth (2005), Ewing & Wunnava (2001) and many other studies.

c) Selecting the maximum lag length (p) of the Unrestricted VAR

We specify a level unrestricted VAR (p) model using the information criteria to select the lag length. Specifically, LR, FPE, and AIC criteria selected a lag of $p = 7$, while SIC and HQIC criteria chose $p = 4$ (Table 2).

$$y_t = b_o + b_1 t + \sum_{i=1}^{p} \psi_i y_{t-i} + \varepsilon_t$$

However, the VAR (4) model seems to have stability problems and serious serial autocorrelations amongst the error terms. Thus, we set our $p = 7$ in the Toda and Yamamoto procedure.



p	*LM-Stat*	p-value
1	35.2793	0.0833
2	36.4804	0.0646
3	33.4526	0.1201
4	13.8500	0.9643
5	33.1339	0.1278
6	20.9649	0.6946
7	19.1256	0.7911
8	18.7914	0.807

Fig. 2: Stability Checks on VAR (7) model

The stability of the inverse roots of AR polynomial of the VAR (7) indicates no root lies outside the unit circle. Furthermore, the test of serial auto correlation on the error terms reveal no serious problem of serial autocorrelation at 5 percent and 10 percent levels. Thus, the VAR (7) model satisfies the two stability conditions (Fig. 2). Before the conduct of the Granger non-causality test, we check the existence of long-run comovement (cointegration) using the bounds test with an autoregressive distributed lag model (ARDL). The choice of ARDL is because of its better performance especially when the finite sample size T is small and the inclusion of different lags of the variables in the model. Furthermore, this method is generally applicable to a mixture of I(0) and I(1) time series (Pesaran, Shin & Smith, 2001). Under this model, we establish a single cointegrated equation of the long-run relationships via ordinary least squares (OLS) by using a bounds testing procedure as proposed by Pesaran *et al.* (2001). We estimated the following differenced VAR (p) model

$$\Delta y_t = -\sum_{i=1}^{p} \lambda_i^{*} \Delta y_{t-1} + \tau^{*} \Delta t_t + \sum_{j=1}^{k} \sum_{i=o}^{p_{j-1}} \Delta z_{j,t-i}{}' \beta_{j,i}{}^{*} - \hat{\phi} EC_{t-1} + \epsilon_t$$

One or more of the monetary policy indicators, *unemployment rate* and *real gdp* variables in the vector z_j is fixed or static, Δ is the first difference operator, Δy_t is the *interest rate* (ir) at first difference,

$$EC_{t-1} = \rho y_{t-1} + c_0 + c_1 t + \sum_{j=1}^{k} z_{j,t-1}{}' \theta_j \ , \ \hat{\phi} = 1 - \sum_{i=1}^{p} \hat{\lambda}_i \ , \ \lambda_i{*} = \sum_{m=i+1}^{p} \hat{\lambda}_m \ , \ \beta_{j,i}{*} = \sum_{m=i+1}^{p_j} \beta_{j,m}$$

Determination of the number of lags was done using the BIC information criterion. This criterion selected an ARDL with three lags of *interest rate*, one lag of *inflation rate*, zero lag of *exchange rate*, one lag of *real gdp* and five lags of *unemployment rate,* i.e. ARDL (3,1,0,1,5). The result of the bounds test is presented in the Table 3 below.

Table 3: Bounds Test results on ARDL (3,1,0,1,5) Interest rate model

I(0) Bound	I(1) Bound	F-stat	k	α
3.03	4.06	6.24	4	10%
3.47	4.57	6.24	4	5%
4.4	5.72	6.24	4	1%

Source: Authors personal computation

Bounds test involves conducting a joint test of hypothesis on the long-run coefficient in the EC_{t-1}. We rejected the null hypothesis of no level long-run relationship since the calculated F-statistic = 6.24 is greater than the asymptotic critical values in Table 3. The estimated long-run level relationships' coefficients and standard errors (in parenthesis) on ARDL (3,1,0,1,5) *interest rate* Model is as follows:.

$$ir_t = -58.21 - 0.08t + 5.99\inf_t + 1.88ex_t + 5.25rgdp_t - 0.56um_t$$

[19.52] [0.02] [1.66] [1.15] [1.67] [0.41]

While *inflation rate* and *real gdp* are significant at all levels of significance with *p*-value = 0.0004 and 0.0021 respectively, exchange rate (*p*-value = 0.1043) and unemployment rate (*p*-value = 0.1665) are not significant in the long-run. However, ϕ = -0.36, which measures the speed of adjustment by the *interest rate* to disequilibrium caused by shocks on the remaining variables is negative and significant at all levels of significance. These shocks could be as a consequence of the various structural breaks observed in the unit-root tests above. For example, a breakpoint of 2011:10 was observed in the *inflation rate* series. A persistent rise in inflation leads to the review of the anchor *interest rate* downward in October 2011. The CBN's instantaneous adjustment in *interest rate* can be explained by the 36 percent speed of adjustment in the equilibrium correction form (Table 4). This model was well specified since there is no serial autocorrelation amongst the error terms. Breusch-Godfrey serial autocorrelation LM test *F* (5,130) = 1.17 (*p*-value = 0.3295) and χ^2 = 6.48 (*p*-value = 0.2622).

Table 4: Equilibrium correction Form for the ARDL (3,1,0,1,5) Interest rate Model

Variable	Coefficient	S.E	t-Statistic	p-value
Δir_{t-2}	0.18	0.07	2.38	0.0185
Δinf_t	-39.88	10.55	-3.78	0.0002
Δex_t	0.68	0.43	1.57	0.1184
$\Delta rgdp_t$	-39.31	10.3	-3.82	0.0002
Δum_t	1.43	1.21	1.18	0.2400
Δum_{t-1}	-0.91	2.6	-0.35	0.7272
Δum_{t-2}	-8.3	2.59	-3.21	0.0017
Δum_{t-4}	-4.64	1.26	-3.69	0.0003
EC_{t-1}	-0.36	0.05	-6.76	0.0000

Source: Author's personal computation

The cointegration test is crucial to the test of Granger non-causality because if two or more time series are cointegrated, there will exist a causality either unidirectional or bidirectional between them but not vice versa. Hence, the bounds test above is a mere check or confirmation of the presence of causality amongst the macroeconomic variables. Note that any of the macroeconomic variables could be used as the dependent variable in the cointegration analysis as long as the model is stable (i.e. the error terms do not have any serial autocorrelations and there are no unit roots in the autoregressive polynomial). Having established the existence of long-run relationships amongst the macroeconomic variables, we proceed to the test of Granger non-causality using the Toda-Yamamoto procedure as proposed by Toda & Yamamoto (1995). We conducted the procedure using p = 7.

Table 5: Granger non-causality test using Toda-Yamamoto Procedure (p = 7), d_{max} = 1

	Variable	χ^2	df	p-value
Dependent variable: ir	inf	17.71851	7	0.0133**
	ex	17.09396	7	0.0168**
	rgdp	18.91609	7	0.0085*
	um	29.1669	7	0.0001*
	All	69.1003	28	0.0000*
Dependent variable: inf	ir	6.0692	7	0.5317
	ex	4.7166	7	0.6945
	rgdp	12.7762	7	0.0778***
	um	7.4421	7	0.3843
	All	35.5113	28	0.1555
Dependent variable: ex	ir	3.7253	7	0.8108
	inf	15.5754	7	0.0293**
	rgdp	16.2485	7	0.0229**
	um	2.1400	7	0.9517
	All	51.7241	28	0.0041*
Dependent variable: rgdp	ir	6.0716	7	0.5314
	inf	11.3708	7	0.1232
	ex	4.6985	7	0.6967
	um	7.4561	7	0.383
	All	31.5554	28	0.293
Dependent variable: um	ir	4.2375	7	0.7521
	inf	25.8322	7	0.0005*
	ex	8.0581	7	0.3275
	rgdp	25.2782	7	0.0007*
	All	41.6011	28	0.0473**

Source: Authors personal computation

These results have implications for policy making. Theoretically, if the five macroeconomic variables have a common stochastic trend, it is expected that bivariate or multivariate causal relationships will exist between them, either unilaterally or bilaterally. Hence, the result of granger non-causality is in line with that of ARDL cointegration test. The test of Granger non-causality (Tables 5 & 6) reveals unidirectional causality amongst the macroeconomic variables except *inflation rate* and *real gdp*. These two macroeconomic variables cause each other (i.e. bidirectional causality exists among them).

Table 6: Summary of Toda-Yamamoto Granger non-causality test

Relation		Direction of causality $p = 7$
interest rate *vs.* inflation rate		*unidirectional*
interest rate *vs.* exchange rate		*unidirectional*
interest rate *vs.* real gdp		*unidirectional*
interest rate *vs.* unemployment rate		*unidirectional*
inflation rate *vs.* exchange rate		*unidirectional*
inflation rate *vs.* real gdp		*bidirectional*
inflation rate *vs.* unemployment rate		*unidirectional*
exchange rate *vs.* real gdp		*unidirectional*
exchange rate *vs.* umemployment rate		*unidirectional*
real gdp *vs.* unemployment rate		*unidirectional*

Source: Authors personal computation

Surprisingly, *interest rate*, *exchange rate*, *inflation rate,* and *unemployment rate* do not cause real gross domestic product either individually or jointly. The case of unilateral causality from inflation to real gross domestic product is in line with the conclusion of Umaru *et al.* (2012). In the interest rate model, all other variables cause *interest rate* individually and jointly. Conversely, only *real gdp* causes *inflation rate*. The *unemployment rate* can better be predicted using the past and current values of the *inflation rate*, *exchange rate,* and *real gdp*. These results confirm the conclusions drawn by some earlier works, as outlined in this paper.

IV. Conclusion

Firstly, by introducing trend break functions in the unit-root tests without a priori information, we have been able to establish a good connection between the various breakpoints and the macroeconomic series. These dates represent critical periods of policy changes by the government and external shocks. The unit-root tests with trend functions suggest that structural breaks in the macroeconomic variable series are very important and significant when formulating economic policies. The breakpoints can be included in a VAR model as deterministic terms to further improve the forecast/ prediction power without affecting the asymptotic properties of the test statistics involved in the analysis. However, the object of the unit-root test is just to establish the order of integration of the time series. Secondly, Granger non-causality tests via the Toda-Yamamoto procedure established bidirectional and unidirectional causal relationships amongst the macroeconomic variables. The existence of causality was confirmed using the bounds test with an interest rate autoregressive distributed lag model. Hence, this study further affirms the conclusions of several other research works that if two or more macroeconomic variables are cointegrated, there *must* be a unidirectional or bilateral causality amongst them but not vice versa. Therefore, we recommend that economic and financial policy makers consider including these macroeconomic variables in the models used for their forecasts.

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